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The Influence of Training on the Stimulus Modality Effect in Delayed Matching to Sample

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THE INFLUENCE OF TRAINING ON THE STIMULUS MODALITY EFFECT IN DELAYED MATCHING-TO-SAMPLE

by

© Darren Fuerst

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ABSTRACT

The purpose of this study was to determine if the stimulus modality effect in successive DMTS by the rat is due to inadequate training procedures. Five male albino (Wistar strain) rats were given a minimum of 3200 DMTS training trials with 2.5 s visual stimulus and a 1 s RI, and 3200 DMTS training trials with 2.5 s auditory stimulus and a 1 s RI. Animals were then trained on bimodal successive DMTS, in which both visual and auditory stimuli could occur, and tested at retention intervals of 5, 10, and 20 s. The results showed that at retention intervals greater than 1 s, retention indices for the auditory sample stimulus either remained at baseline levels of performance (hits), or declined less than retention indices for the visual sample stimulus (false alarms and P(A) scores), indicating better retention of auditory stimuli. Thus, contrary to expectations, extensive training did not eliminate the stimulus modality effect. However, supplementary analyses indicated that: 1) for three of five animals during bimodal DMTS training retention of the auditory sample stimulus was greater than retention of the visual sample stimulus; 2) during unimodal DMTS training, animals reached a criterion level of performance about three times faster with visual sample stimuli as compared to auditory sample stimuli. These results were interpreted as modest support for the hypothesis that the stimulus modality effect is due to a failure to accurately encode auditory stimuli, rather than functional properties of working memory (such as decay rate or retrieval) in the rat.

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CHAPTER I

Introduction

There can be little doubt that, over the short history of modern psychology, behaviorism has been one of the more popular, and productive, approaches to an understanding of why organisms act in a particular way. Indeed, many concepts derived from the behavioral approach are particularly noteworthy for their applicability across a range of species and phenomena. However, with increased sophistication in experimental psychology has come a realization that "black box" approaches cannot adequately account for a wide variety of behaviors. This awareness, to a large extent, began with questions about complex human behaviors, such as language, problem solving, and behavior disorders. In such instances, it became obvious that an understanding of processes "inside the box" was necessary to establish a correspondence between observed input and output states. The wealth of published research, and the ongoing activity in the area of human cognition is indicative of the progress which has been made in this area (Anderson, 1980).

It general, it is for these two reasons (limitations of behavioral approaches and significant progress in the investigation of human cognition) that cognitive aspects of animal behavior have come under increased scrutiny (Domjan & Burkhard, 1982). While cognitive approaches to the study of animals were long regarded as being of dubious validity, over

the past twenty years or so, there has been a growth of interest in this area. Not surprisingly, some research in this field has addressed "complex" cognitive processes in animals which correspond to human cognitive processes. Perhaps the best known, and most controversial, of these processes is language capacity in non-human primates (for example, Patterson 1978; Premack, 1976; Terrace, 1979). Other researchers have examined concept formation (for example, Herrnstein, Loveland & Cable, 1976), or, at a less complex level, serial pattern learning (Capaldi, Verry & Davidson, 1980). However, as in research dealing with human cognition, one of the most popular and wide-ranging topics of investigation has been memory processes in animals, and it is with animal memory that this paper is concerned.

Memory: General Definitions and Concepts

Before turning to the issues of concern in this paper, a more specfic definition of the term "memory", and in particular "working" or "short-term" memory, is needed. It is common in everyday life to state that an organism "remembers" if its behavior in a current situation is influenced by a previous event. As Weiskrantz (1968) has noted, however, this definition is not adequate. For example, if a blind person walks in front of a moving car, one would certainly not conclude that this behavior is due to "memory" of the event which produced the blindness. Memory, according to Weiskrantz (1968), occurs when an event leaves some change in the nervous system (a "trace") which an organism can relate or associate to a present event.

From this definition it is obvious that "learning" and "memory" are closely related. Weiskrantz (1968) has argued that the two can be distinguished in that the study of learning is concerned with the establishment of relationships between traces, whereas the study of memory is concerned with the behavior of traces after the relevant associations have been formed.

It is common in cognitive psychology to subdivide memory into two general types: "long-term" or "reference" memory, and "short-term" or "working memory". Reference memory is concerned with constant relationships which do not vary across a testing situation (Weiskrantz, 1968). It refers to the retention of information necessary for correct performance on all trials of a task (Honig, 1978). Working memory is concerned with unique relationships which apply among a set of events on a single occasion only (Weiskrantz, 1968). It refers to the retention of information necessary for accurate performance on a single trial of a task (Honig, 1978). Reference and working memory have received about equal attention in human cognitive research; however, animal cognitive research has focussed primarily on working memory.

Honig and Thompson (1982) have proposed that working memory be further subdivided into "retrospective" and "prospective" memory processes. Retrospective memory refers to the retention of a representation of a stimulus over a period of time ("retention interval"). This representation allows a subject to make a correct response decision at a later point in a trial. As retrospective memory is of primary concern in this

paper it will be dealt with in greater detail below. Prospective memory, on the other hand, is an anticipatory process. It is the maintenance of a response decision over a period of time, until conditions allow execution of that response.

Honig and Thompson (1982) argued that prospective memory processes are of primary importance in a number of experimental paradigms. The common feature between such paradigms is that an initial stimulus provides sufficient information for an animal to "solve" a task (select the correct response). Such paradigms are, perhaps, best demonstrated by simple delayed discrimination tasks (Hunter, 1913; Honig & Wasserman, 1981). However, interpretations based on the notion of prospective processes have also been applied in more complex preparations, such as simultaneous delayed matching to sample and delayed conditional matching tasks. In simultaneous delayed matching to sample, an initial sample stimulus indicates which of two test stimuli will be correct at the end of the retention interval. Typically, the two test stimuli are randomly associated with two manipulanda (such as keys or levers) to which the animal may respond. In simultaneous delayed matching to sample, there is a direct mapping of sample and test stimulus characteristics (i.e reinforced stimulus pairs are identical, or nearly so), whereas in delayed conditional matching the relationship is arbitrary (for example, a red light may be mapped onto a black square). In either case, it has been argued that the sample stimulus may allow the animal to code response instructions

regarding the test stimuli (such as "peck the red key"), which will be emitted at the end of the retention interval (Honig & Thompson, 1982; Kraemer & Roberts, 1984). However, empirical differentiation of retrospective and prospective processes by these paradigms remains problematic.

Successive DMTS and Retrospective Memory

Simultaneous or two-choice delayed matching to sample is not the only preparation which can be used to study short-term memory processes in animals. This is fortunate, as there are (at least) two significant problems with the simultaneous DMTS technique. First, as the test (choice) stimuli must be located in different places, any position preferences which the animal may develop will invariably influence performance (Konorski, 1959; Wasserman, 1976). Position preferences also raise the problem of trying to differentiate the importance of the sample stimulus (and any transformations it may undergo) and the influence of stimuli which may be associated with a particular position or orientation. Second, as two (or more) choice stimuli are presented at testing, nonvisual stimuli cannot be used. For example, two or more sounds or odors presented simultaneously would probably interact and not produce discrete sensory signals (Wasserman, 1976). Furthermore, as many forms of nonvisual stimuli cannot be accurately localized in space, problems may arise where test stimuli must be associated with particular manipulanda. The use of different responses for particular matching rules is also problematic, as it is difficult to equate responses according to task demands.

It is for these reasons that some researchers have adopted a DMTS paradigm first proposed by Konorski (1959). In the original Konorski technique, stimuli within one modality (for example, high and low tones) are presented in pairs, one after another, with a short delay (retention interval) between the stimuli. Thus, where S_x and S_y represent different stimuli, four stimulus pairs or combinations can result: S_x-S_x, S_y-S_y, S_x-S_y, and S_y-S_x. In the Konorski paradigm, only matching stimulus pairs (S_x-S_x, S_y-S_y) are reinforced (in either the operant or classical conditioning sense), whereas nonmatching stimulus pairs (S_x-S_y, S_y-S_x) are not. The advantages of this technique are obvious. Due to the successive presentation of discrete stimulus events nonvisual stimuli can be used without concern over interaction of sensory signals (Wasserman, 1976). Indeed, as will be seen below, variants of the technique can be used in which stimuli differ across modalities (such as light and tone), rather than just within modalities (such as high and low tones). As (typically) only a single response is required of the animal, on a single manipulandum, position and orientation preferences cannot affect an animal's performance. Furthermore, at least in theory, for correct performance of the task an animal must retain information specific to the first stimulus (such as tone pitch) over the retention interval.

Of course, an experimental paradigm is of little use if it is too difficult for subjects to master (reach some reasonable criterion level of performance). While the Konorski paradigm has not been used to the extent of other matching to sample

techniques, there is some evidence that a variety of animal species are capable of acquiring the task. For example, Chorazyna (1959) and Chorazyna and Stepien (1961) found that dogs could learn to respond to matching tone pairs, and not to respond to nonmatching tone pairs, separated by a three second interstimulus interval. However, delay intervals greater than three seconds produced an (unspecified) deterioration in performance. Stepien, Cordeau and Rasmussen (1960) found that African Green monkeys could master successive DMTS with click stimuli differing in pulse rate. These authors also reported that the monkeys were able to transfer this discrimination to visual stimuli (flashing lights). However, this acquisition and transfer of a "matching rule" from the auditory to visual modality has proven very difficult to replicate (D'Amato & Colombo, 1985; Thompson, 1980). Pigeons readily learn the task with visual stimuli, such as colored key lights (Wasserman, 1976) or lines of different orientation (Shimp & Moffit, 1977), and the "matching rule" may generalize to novel stimuli (Urcuioli & Nevin, 1975). Overall, it would seem that successive DMTS is yet another tool which cognitive researchers can use in the study of memory processes in these animals.

The situation is somewhat different with respect to investigations which utilize the laboratory rat. As Wallace, Steinert, Scobie and Spear (1980) noted, very little is known about the retention of recent events by rodents. As the rat is not a "visual" animal to the same extent as other commonly studied species, simultaneous DMTS tasks cannot be used

(Wallace et al., 1980). This is unfortunate, as there is a considerable amount of information available on behavioral and physiological features of learning in rodents. Wallace et al. (1980) set out to determine whether laboratory rats could acquire an adaptation of the Konorski successive matching to sample procedure. Ten food-deprived Fischer 344 rats were trained to press a retractable lever presented coincident with an auditory ("A": 4,000-kHz tone) or visual ("V": 15-W light) stimulus for reinforcement (food pellets). When the initial response was acquired, presentation of the lever and test stimulus was preceded by a five second visual or auditory sample stimulus. If the sample and test stimuli matched (V-V, A-A) a response on the lever produced reinforcement. A response to nonmatching stimulus pairs was never reinforced. Three interstimulus or retention intervals were used in the study: 0 (0.25 s), 2, and 5 seconds, presented in a random order within daily trials.

The task was quickly mastered by the animals, with seven of ten rats reaching and maintaining a criterion level of performance at 0 s delay within 10 days (960 trials). Also, at this retention interval, there was no difference between the retention of auditory versus visual stimuli. However, with increased retention intervals there was a significant deterioration in performance, with a much greater reduction in matching to the visual stimulus compared to the auditory stimulus at the 5 s retention interval. This result was quite surprising. As Wallace et al. (1980) noted, the finding of

specific aspects of the stimulus to be remembered ("content", as contrasted with, for example, duration) affecting the rate of forgetting is rare. Indeed, some previous research had indicated the presence of common mechanisms for the retention of stimuli, responses, and reinforcers in pigeons (Maki, Moe & Bierly, 1977). Wallace et al. (1980) speculated that rats may encode auditory information more efficiently than visual information: an interpretation which, while untested, seemed consistent with the limited visual capabilities of the rat.

Of course, had the findings of Wallace et al. (1980) remained an isolated result in the animal cognition literature the stimulus modality effect in rat working memory would have remained little more than a curiosity. However, the finding of better retention of auditory as opposed to visual stimuli has been replicated with a different type of laboratory rat and some procedural variations. Cohen, Escott and Ricciardi (1984) reported two experiments which had the main purpose of investigating possible response biases which may arise from the successive DMTS paradigm (for a further discussion of this issue, see Data Analysis in the Method section below). In the first study conducted by Cohen et al. (1984), six albino (Wistar) rats were trained on asymmetrically reinforced successive DMTS (in which only responses to matching stimulus pairs were reinforced), and six animals were trained on symmetrically reinforced successive DMTS (in which nonresponses to nonmatching stimulus pairs were reinforced, as well as responses to matching stimulus pairs). Stimuli consisted of

light (five 6-W ceiling lights) and/or tone (2.8 kHZ) separated by a 1, 2.5, 5, or 10 s interstimulus interval.

The investigators found that, overall, there was a decrease in retention of the visual sample stimulus relative to the auditory stimulus at retention intervals of 5 and 10 s, regardless of reinforcement symmetry. This was due to a decrease in the proportion of reinforced lever presses to the visual sample stimulus relative to baseline performance (decrease in "hits"), and a greater increase in nonreinforced responses ("false alarms") to a visual sample stimulus relative to baseline and auditory sample stimulus performance. In the second study, a replication of the first using a within-subjects design and retention intervals of 5, 10, and 20 s, exactly the same effects for stimulus modality were found (with some exceptions in the details of the effect of reinforcement symmetry). Cohen et al. (1984) argued that these results supported the notion of two separate, modality specific, short-term storage systems, each possessing different characteristics of decay and retrieval. Presumably, the comparatively poor retention of a visual stimulus is due to faster decay in, or more difficult retrieval from, visual short-term memory relative to auditory short-term memory.

Stimulus Modality Effect: Retrospective Process?

The argument presented by Cohen et al. (1984) rested on three assumptions not directly supported by their study. As the remainder of this paper concentrates on these assumptions and possible alternatives, for purposes of clarity they will be

summarized at this point:

1. The first assumption is that performance in successive DMTS tasks is determined primarily by retrospective memory processes with prospection taking a minor or negligible role. This assumption is based on a "rational" analysis of the task requirements of successive DMTS. Theoretically, since the sample stimulus does not provide sufficient information to "solve" the task (select a response), the animal must retain information about the nature of that stimulus during the retention interval, so that it can be compared to the test stimulus. Retention of specific information about the sample stimulus is, by definition, a retrospective process.

2. The second assumption is that the stimulus modality effect is determined primarily by retrospective processes. If retrospective processes dominate successive DMTS performance, and if the stimulus modality effect is characteristic of performance in that task, it seems logical to propose that the stimulus modality effect is due to retrospective memory processes.

3. The third assumption is that the rat has (at least) two separate, modality specific, short-term storage systems. From this assumption it follows that differential retention of light and tone stimuli could be due to functional differences between the two systems. As stated above, Cohen et al. (1984) proposed that the two systems may differ in decay rate and/or retrieval.

Of course, assumptions need to be tested lest they remain little more than idle speculation. Fortunately, Cohen, Galgan

and Fuerst (1985) have conducted a series of studies which test the first two points listed above. With respect to assumption 1 (that performance in successive DMTS is primarily to retrospective processes) they noted that it should be possible to differentiate retrospective and prospective processes by varying the information imparted by the sample stimulus and the complexity of the response rule: To this end, twelve albino rats were divided into two groups of six animals. One group received training on successive DMTS with light and tone stimuli. The other group was trained on a delayed simple discrimination task (DD) in which animals were reinforced for a response to any test stimulus, provided it was preceded by a specific sample stimulus. Thus, three animals were reinforced for responses on trials initiated by a light (sample) stimulus (regardless of the modality of the test stimulus), and three animals were reinforced for responses on trials initiated by a tone stimulus. It was argued that, since the sample stimulus provided all the information necessary to solve the task (response choice), animals in the DD condition would simply prospect whether or not to respond to the test stimulus. On the other hand, the sample stimulus in the DMTS condition would not provide sufficient information for the animal to select a response, and the animal would have to retrospect the nature of the sample stimulus when presented with the test stimulus. Furthermore, each animal received both asymmetrically reinforced (reinforcement contingent on correct response only), and symmetrically reinforced (reinforcement contingent on both

correct responses and correct omissions of response) versions of the tasks. Cohen et al. (1985) argued that performance in a prospection dependent task should decline more rapidly over increased retention intervals (5, 10, and 20 s) in the symmetrical reinforcement condition due to the greater complexity of the response rule which must be prospected. On the other hand, performance in a retrospection dependent task should be comparatively unaffected by changes in the complexity of the response rule.

Overall, the results of the study were consistent with these predictions. Reinforcement symmetry influenced retention scores most consistently in the DD condition, where scores declined with increased retention intervals more in the symmetrically than asymmetrically reinforced versions of the task. Furthermore, there were no significant differences between light and tone stimulus retention in the DD task. In the DMTS condition, there was, in general, no effect of reinforcement symmetry. However, as in previous research, retention of visual stimuli was significantly worse than retention of auditory stimuli in the DMTS task. Thus, it was concluded that performance in successive DMTS is indeed primarily dependent on retrospective processing, as increased complexity of response rules did not produce a comparable decline in retention scores. Such manipulations did, however, result in a deterioration of performance in DD, as predicted by the retrospective/prospective model of working memory and a rational analysis of task demands. Thus, there is experimental

evidence to support the first assumption stated above.

While the stimulus modality effect observed in successive DMTS was consistent with both previous research and a retrospective model of DMTS performance, it did not necessarily support the assumption that the effect is due to retrospective memory processes. As Cohen et al. (1985) pointed out, an alternate prospective account for the effect is that rats are less able to maintain a response instruction to a visual test stimulus prompted by a prior sample stimulus, than to maintain a response instruction to an auditory test stimulus prompted by a prior sample stimulus. In this case, the stimulus modality effect would be dependent on the modality of the test stimulus, rather than the modality of the sample stimulus. However, an analysis of retention according to sample stimulus modality would incorrectly indicate worse retrospective retention of light as compared to tone, as in the DMTS task reinforced trials with a light sample stimulus are always paired with a light test stimulus. Cohen et al. (1985) argued that if this hypothesis is correct, a reversal of reinforcement contingencies (wherein mismatched stimulus pairs are reinforced, and matched pairs are not) should produce a corresponding reversal of the stimulus modality effect, in that retention of an auditory sample stimulus should appear to be worse than retention of a light stimulus. This would be due to the fact that the (hypothetically) more difficult to remember prospective rule to respond to a light test stimulus would now be paired to a tone sample stimulus.

To test this hypothesis, 14 albino rats were divided into two groups. One group received training and testing on successive DMTS, in which reinforcement was contingent on responses to matching light and tone stimuli. The second group was trained and tested on a delayed mismatching to sample task (DMmTS), in which reinforcement was contingent on responses to mismatching light and tone stimulus pairs (L-T, T-L). Both groups were tested at retention intervals of 5, 10, and 20 s. An analysis of the data by sample stimulus modality indicated that, in both groups, retention of the light sample stimulus was significantly worse than retention of the auditory stimulus at delays greater than baseline (1 s). Thus, reversal of the correspondence between test stimulus modality and response rules failed to reverse the effect of modality of the sample stimulus. Cohen et al. (1985) concluded that these results clearly supported a retrospective rather than a prospective account of the stimulus modality effect in DMTS (assumption 2).

Statement of the Problem

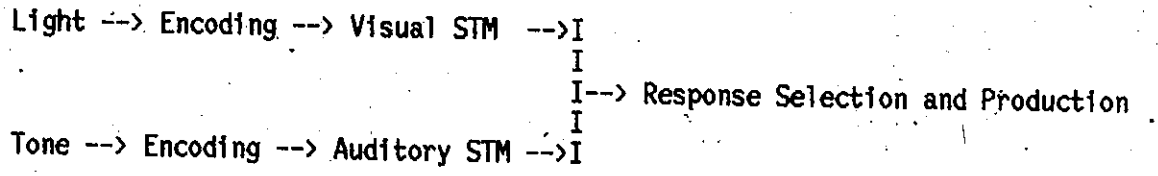
To summarize to this point, the stimulus modality effect in successive DMTS would appear to be a consistent feature of performance in that task. While DMTS has not been extensively investigated in the rat, all available literature in this area has reported the effect (Cohen et al., 1984; Cohen et al., 1985; Wallace et al., 1980). A possible mechanism underlying the effect has been proposed by Cohen et al. (1984); however, this proposal was based on certain assumptions about the processes involved in successive DMTS, and the organization and

functional characteristics of rat working memory. Two of these assumptions have indeed received some experimental support. First, there is evidence that performance in successive DMTS is primarily dependent on retrospective memory processes, as manipulations of response rule complexity do not affect retention in DMTS (Cohen et al. 1985). Second, there is evidence that the stimulus modality effect observed in successive DMTS is due to retrospective (as opposed to prospective) memory processes, as manipulations of the contingency between stimulus pairs and reinforcement do not produce corresponding changes in the nature of the effect: retention of light remains worse than retention of tone (Cohen et al. 1985).

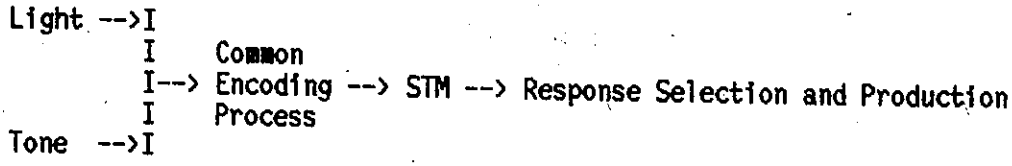
Clearly then, explanations of the stimulus modality effect must take into account retrospective aspects of rat short-term memory. The particular hypothesis under consideration, the Cohen et al. (1984) proposal, does, of course, meet this requirement. However, their assertion that the effect is due to different decay rates and/or retrieval capability rests on the assumption that there is a modality specific organization in rat short-term (retrospective) memory (assumption 3, above). As noted by Cohen et al. (1984), the notion that information from different sensory systems is retained in modality specific short-term stores is contrary to some theories of short-term memory in humans. A number of researchers in the area of human memory have proposed that information in human short-term memory is stored in a more general, nonmodality specific form.

For example, Anderson (1980) argued that information in human working memory consists of activated propositional-codes, rather than specific physical details of sensory input. A similar idea has been expressed by Massaro (1975), who proposed that information held in short-term modality specific stores may be processed into non-specific "Generated Abstract Memory" for further analysis and retention over longer intervals.

From the preceding notions of a general encoding system in human memory, it may be argued that the assumption of (at least) two separate modality specific stores for visual and auditory information in rats may be inaccurate. At the risk of oversimplification, the model proposed by Cohen et al. (1984) ("model 1") could be represented in the following manner:



However, it is also possible that incoming sensory information may be encoded into a more general, nonmodality specific form in working memory. In this case, a simple representation of this model ("model 2") would be:



It must be kept in mind that these representations of the two alternatives are not meant to convey complete or accurate models of animal working memory; they are simply heuristic devices. When the two models are compared, it would seem that

model 2 may be a somewhat more parsimonious representation. This is clear if one considers two problems associated with model 1. First, the logical implication of separate visual and auditory STM stores is that each sensory modality may therefore be represented likewise. Thus, is there separate storage for olfactory, gustatory, tactile, nociceptive, proprioceptive, interoceptive, and kinesthetic stimuli as well? Second, how does one demonstrate that these separate modality specific stores do or do not exist? In these respects, the notion that stimuli undergo some form of common encoding and storage is an attractive one.

However, if one accepts that incoming sensory information may be encoded and retained in a non-modality specific working memory, how can the stimulus modality effect be accounted for? If both light and tone information are stored by a general process, different decay rates or retrieval effectiveness cannot be invoked as explanations, as these mechanisms would affect light and tone information in a similar fashion. A more likely explanation is that the stimulus modality effect results from a failure to accurately encode the relevant properties of the stimuli. In other words, the animal cannot retain information which it never processed into working memory in the first place. This raises the question, which stimulus modality could be improperly coded?

Given that light stimuli are more poorly retained than tone stimuli, it may, at first glance, seem logical to conclude that visual information is less accurately encoded than

auditory information. This was the argument proposed by Wallace et al. (1980). However, there is evidence from studies of discriminative compound stimuli which is inconsistent with this idea. For example, studies on reciprocal overshadowing in operant paradigms have shown that light stimuli are more salient to rats than tone stimuli (Cohen, Mehan, & Shpuniarsky, 1984). In other words, light stimuli consistently "capture" more attention or associative strength when presented as a compound stimulus with tone. Therefore, it is difficult to conclude that light is more poorly encoded than tone.

Thus, it seems logical to argue that tone is more poorly encoded than light. However, why should this produce apparently worse retention of light than tone? The answer is quite simple when the successive DMTS task is broken down into components according to stimulus modality. Table 1 presents an "ideal state" in DMTS, with perfect encoding and retention of stimuli. In this case, the animal responds appropriately to matching stimulus pairs and thus scores a high proportion of hits, and fails to respond to nonmatching stimulus pairs, which produces a low proportion of false alarms. This is the typical interpretation of an animal's performance at baseline levels of delay. On the other hand, Table 2 presents the outcome where there is an indeterminate or inaccurate encoding of tone stimuli, and decay or degradation of the representation of light stimuli with increased retention intervals. In this case, the animal fails to encode the relevant properties of the tone stimulus, and retains an indeterminate or unarticulated

Table 1

Model 1: Perfect Encoding and Retention

S_1	S_2	Response	Outcome	Conclusion
Tone	Tone	Press	High Rate Hits To T S_1	Good Tone
Tone	Light	Do Not Press	Low Rate False Alarms To T S_1	Retention
Light	Light	Press	High Rate Hits To L S_1	Good Light
Light	Tone	Do Not Press	Low Rate False Alarms To L S_1	Retention

Table 2

Model 2: Indeterminate Encoding of Tone and Degradation of Light Sample Stimulus With Increased RI

S_1	S_2	Response	Outcome	Conclusion
?	?	Press	High Rate Hits To T S_1	Good Tone
?	Light	Do Not Press	Low Rate False Alarms To T S_1	Retention
L --> ?	Light	Do Not Press	Low Rate Hits To L S_1	Poor Light
L --> ?	?	Press	High Rate False Alarms To L S_1	Retention

representation (indicated by "?" in the table). Of course, one cannot specify the nature of this representation; the animal may simply "know" that a stimulus ("?") has occurred. Light stimuli are accurately encoded, but with increased delay the representation of the sample stimulus can be presumed to degrade or decay. In this case, the animal may not respond to a L-L combination because the representation of the sample stimulus no longer matches the test light (in effect, a L-L pair becomes ?-L). In the case where a L-T combination is presented, the animal may incorrectly respond, because, through degradation of light and indeterminate encoding of tone, the stimulus pair has effectively become ?-? (i.e. the animal may simply retain the information that two stimuli have occurred, and that they may match). This would produce a high rate of false alarms to nonmatching stimulus pairs that begin with light. However, when T-T is presented, degradation and indeterminate encoding of tone may produce traces sufficiently similar (?-?) that the animal responds, and thus scores a comparatively high rate of hits to the tone sample stimulus. On the other hand, with nonmatching stimulus pairs that begin with tone, accurate encoding of light would result in the animal not responding, and a low rate of false alarms to the tone stimulus on nonmatching trials. The net effect of these processes is that tone would appear to be better retained than light, even though tone is not accurately encoded and retained in working memory.

If these propositions are accepted as a working model of

rat short-term memory and the stimulus modality effect, the question then becomes: why is tone more poorly or inaccurately encoded than light? Rats are capable of retaining the characteristics of a tone stimulus, as indicated in the delayed discrimination task reported by Cohen et al. (1985). Why might they not do so in successive DMTS? The answer may lie in the training procedures which are used during DMTS acquisition. Typically, once an animal has been shaped to bar press, it is presented with all of the four possible stimulus pairs (L-L, T-T, T-L, and L-T) within each daily block of trials. The only difference between training and testing procedures lies in the length of retention interval (1 s or less), and a non-random order of stimulus-pair presentation. Given that light tends to have greater salience and overshadow tone, the animal may never come to attend to tone to the extent which it does to light, since 75% of all trials will involve a light stimulus. In a sense, it may "learn" to attend to and encode only a subset of the relevant stimulus information which is available in the task.

Purpose and Design

The purpose of this study was to determine if the stimulus modality effect in delayed matching to sample is indeed due to training procedures. Considering that the simultaneous presentation of light and tone stimuli in typical successive DMTS training procedures may interfere with accurate encoding of tone stimuli in subsequent testing trials, animals in this study received separate training with each stimulus modality

(light and tone). Furthermore, animals were given massed practice on matching within each modality. Each animal received a minimum of 680 DMTS trials with each modality before being trained and tested on "standard" successive DMTS with both light and tone stimuli. As the training procedures were designed to enhance the subjects' processing of tone stimuli, differences in delayed matching to sample based on S_1 modality should be eliminated.

CHAPTER II

Method

Subjects

Subjects consisted of eight male albino (Wistar strain) rats, approximately 150 days old, obtained from the University of Windsor breeding colony. All animals had previously served as subjects in a conditioned (lick) suppression study of contextual cues. One animal was dropped from the study in the early stages of training after failing to acquire DMTS with unimodal stimuli (tone) after a training period of 60 days. A second animal was dropped from the study after failing to reach the criterion level of performance during unimodal DMTS reacquisition. A third animal was discarded for failure to reach criterion on bimodal DMTS (light and tone stimuli) despite an extended period of training (approximately five months). The remaining five animals successfully completed all phases of the study.

Animals were individually housed with ad lib access to food. Fifteen minutes free access to water was provided 30 minutes after the completion of each daily experimental session. The animals were maintained on a 12 hour dark/light cycle, and were run during the dark period.

Apparatus

Four standard (BRS/LVE) small animal operant chambers were used. Each chamber was equipped with a retractable lever and

0.05 ml water dipper mounted on one wall, five 24 volt six-Watt incandescent lights mounted in the ceiling, and a Mallory Sonalert tone generator. Each operant chamber was housed within a standard (BRS/LVE) light and sound attenuating isolation chamber whose ventilation fan produced a constant 55db masking noise.

Two 2.5 s stimulus events were used in the study: a 2.8 kHz 75db tone from the Mallory Sonalert tone generator, and onset of the cage lights. The operant chamber remained dark at all other times. The room in which the chambers were housed contained an external speaker which emitted 62db white noise to further mask incident noise from the corridor and adjacent control room. Program control and data acquisition was managed by conventional electromechanical equipment.

Procedure

Preliminary Training. After three days of handling and maintenance on water deprivation schedules, the rats were shaped, by approximation training, to press a lever extended into the illuminated chamber for 0.05 ml. droplets of sweetened water (0.10% Sodium Cyclamate by weight per unit volume). Training continued until each animal made 200 unassisted presses. Once the basic response had been learned the cage lights were extinguished for the remainder of this phase. During the next eight sessions, the animals were presented with the retractable lever every 30 seconds, for 100 trials. A press on the lever produced reinforcement and retracted the lever.

The time available to the animal to press before the lever retracted decreased from 15 seconds to five seconds over these sessions. No cue, other than the sound of the lever drive motor, was presented during these trials.

Unimodal DMTS Training. Table 3 presents a summary of the stages of the experiment beyond the pretraining phase. After the animals had completed lever-press training, they were divided into two groups of four animals. Each group was then given DMTS training in which a single stimulus modality, either light or tone, was presented. Thus, half of the animals were initially trained with a light stimulus, and half were initially trained with a tone stimulus. Each trial consisted of of an initial 2.5 s stimulus (S_1), a one-second inter-stimulus-interval (ISI), followed by a second 2.5 s test stimulus (S_2). Concomitant with the onset of S_2, the retractable lever was introduced to the cage, and remained out for a maximum of five seconds, or until the animal pressed. Daily training sessions consisted of 100 such trials, separated by a 24 s inter-trial interval (ITI) measured from offset of S_2 to onset of next S_1. The number of trials per session (100), the duration of stimulus presentation (2.5 s), and the ITI remained constant throughout the remainder of the experiment.

Within a block of 100 training trials, the animals were presented with 50 matching and 50 non-matching stimulus pairs. Thus, in the group initially trained with light stimuli, each animal was presented with 50 Light-Light stimulus pairs, 25 _(no stimulus)-Light pairs, and 25 Light-_ stimulus pairs. Only

Table 3

Summary of Procedure Beyond Pretraining Phase

Phase	Stimulus Presentation Condition	Duration	Stimulus Modality	
			Group A	Group B
Unimodal DMTS Training	10 X SO	14 Days	Light	Tone
	5 X SO	14 Days	Light	Tone
	Random SO	To Criterion	Light	Tone
	10 X SO	14 Days	Tone	Light
	5 X SO	14 Days	Tone	Light
	Random SO	To Criterion	Tone	Light
Unimodal DMTS Reacquisition	Random SO	To Criterion	Light	Tone
	Random SO	To Criterion	Tone	Light
Bimodal DMTS Training	Random SO	To Criterion	Light and Tone	
Retention Testing	Random SO	2 Sessions Per RI Plus Retraining To Criterion	Light and Tone	

Note. SO = Stimulus Order

a response to L-L could produce reinforcement. In the same fashion, animals first trained with tone stimuli were presented with 50 Tone-Tone, 25 _-Tone, and 25 Tone-_ stimulus pairs, with T-T being the reinforced combination. The order of presentation of stimulus pairs (Stimulus Order or SO) was also varied across training sessions. At the start of training, matching and non-matching stimulus pairs were presented in blocks of 10 consecutive trials. In other words, 10 matched stimulus pairs would be followed by 10 non-matched stimulus pairs, and so on, for 100 trials ("10 X SO"). This condition was in effect for 14 days (1400 trials). The SO was then reduced to five consecutive trials (i.e. five matched trials followed by five non-matched trials). This condition ("5 X SO") remained in effect for 14 days (1400 trials). At the end of this period, the SO was changed such that the sequence of stimulus pairs was presented in a random order ("Random SO").

All animals remained in the Random SO condition until their level of performance reached criterion. In this study, criterion level of performance was defined as 75% correct responses in each of two consecutive sessions (200 trials total), provided that at least 60% of available reinforcements were collected in each session. Thus, each animal had to make at least 30 reinforced presses (out of a maximum of 40 total responses in this case) in both of two consecutive sessions. If a more simplistic criterion of 75% correct responses over two sessions had been adopted, it would have been possible for an animal to reach such a level of performance even though its

number of reinforced presses was equal to or less than the number of failures to respond correctly.

After reaching criterion on Random SO, animals were switched to training in the opposite stimulus modality. Thus, an animal originally trained on DMTS with a light stimulus now received DMTS training with a tone stimulus, and vice versa for animals initially trained with tone. As in the first part of unimodal DMTS training, the animals received 14 days of 10 X SO, and 14 days of 5 X SO, before being presented with a random sequence of light or tone stimulus pairs. When animals reached criterion (as defined above) in the Random SO condition, they completed this phase of the study.

Unimodal DMTS Reacquisition. Following the initial period of unimodal DMTS training, the animals were retrained in the stimulus modality to which they had originally been exposed. In this phase, only the random order of stimulus presentation was used. Animals were run under this condition until their performance reached criterion level. After this, the animals were switched to the opposite stimulus modality, and once again retrained using the Random SO until performance reached criterion. At this point, the animals were considered to have acquired unimodal delayed matching to sample with light and tone stimuli, at retention intervals of 1 s.

Bimodal DMTS Training. Following unimodal DMTS training, in which only a single stimulus modality was presented in each session, the animals received training sessions in which both light and tone stimuli were presented. In this condition, there

were four possible pairs of light and tone stimuli: 1) Light-Light, 2) Tone-Tone, 3) Light-Tone, and 4) Tone-Light. Combinations 1 and 2 were the reinforced stimulus pairs, and 3 and 4 were the non-reinforced stimulus pairs. Each combination occurred 25 times per session (for a total of 100 presentations per session). As in unimodal DMTS training, the retention or inter-stimulus interval remained constant at 1 s. A random sequence of stimulus pairs was presented until animals reached the criterion level of performance. Once this was attained, the animal was considered to have acquired the bimodal DMTS task.

Retention Testing. The retention of S_1 was tested at three retention intervals (RI) of 5, 10, and 20 s in the following manner. Having reached criterion in the previous two DMTS training sessions, each rat received a block of 200 test trials (100 trials per day) in which the interval between S_1 and S_2 was increased to 5 s on every trial. Following this, each animal was retrained to criterion with a 1 s ISI, then tested over 200 trials with a 10 s RI. Once again, animals were retrained to criterion with a 1 s ISI, then given the final block of 200 test trials with a 20 s RI.

Data Analysis. Prior to receiving a block of 200 test trials, an animal had to attain a criterion level of performance on a block of 200 training trials (RI of 1 s). Data from these training trials provided a baseline level of performance against which an animal's performance on 200 test trials could be compared. Each retention and baseline block of trials consisted of 100 matching and 100 non-matching stimulus

pairs, of which half began with an auditory S_1 and half with a visual S_1. From the data acquired during these trials the proportion of reinforced lever presses (hits) and non-reinforced lever presses (false alarms) out of 50 possible responses on each type of S_1 modality (light or tone) were calculated and recorded for each animal. Although comparisons of proportions of hits and false alarms under the different conditions of DMTS training and testing formed a part of the data analysis of this study, these measures were not of primary concern. Instead, the principle dependent measure used in this study was $P(\bar{A})$, which is a variable derived from signal detection theory (TSD). As this is not a common procedure in animal experimentation, the use of a TSD based measure requires some justification and explanation.

In psychology, TSD is perhaps most commonly associated with the investigation of perceptual processes in humans. One frequent application of TSD is in the determination of a subject's sensitivity or ability to detect the presence of a signal which is combined with noise. In this case, TSD assumes that the sensory states (such as neural excitation) of the subject are normally distributed. Given that there are two conditions, noise alone (no signal) and signal plus noise, there are two such normal distributions: one for each condition. Considering the properties of the normal distribution, it is possible, using hit and false alarm rates, to calculate the separation of the noise and signal plus noise distributions. This value, known as d', is a measure of the

sensitivity of the subject. The most important characteristic of this measure is that it provides an index of sensitivity which is independent the subject's decision or response bias (the willingness of the subject to respond independent of signal sensitivity).

The use of d' has not been restricted to the study of perceptual sensitivity in humans. It has also been applied to the study of many different cognitive processes as well. As Massaro (1975) has noted, TSD derived measures are applicable in any experiment in which an index of performance is required which is free from decision bias. Thus, d' is particularly useful in the investigation of human working memory, and has been applied to a number of problems in this area (for a number of examples, see Massaro (1975)). The general assumption is that, in this case, the "signal", rather than being an immediate sensory event, is instead some form of memorial representation imposed upon background neural activity in working memory. Thus, d' can be used as bias-free measure of stimulus retention in working memory.

The investigation of animal working memory using successive DMTS is precisely such a situation in which an unbiased index of retention is required. As Weiskrantz (1968) has noted, succesive DMTS tends to promote a general bias to respond which could result in the underestimation of S_1 retention. This is because reinforcement is typically provided in an asymmetrical payoff structure, in which only hits, and not correct ommissions as well, are rewarded. Thus, if the

animal is uncertain as to the match between S_1 and S_2, it "pays" the animal to respond on the chance that it may be reinforced, as a failure to respond is never rewarded. Cohen et al. (1984) found empirical evidence to support this position, in that both failures to respond and incorrect responses were reduced by a symmetrical payoff structure. With increased RI's, such a bias to respond (in asymmetrically reinforced DMTS) would tend to produce artificially rapid decrements in retention indices which do not take the animal's decision criterion into account.

Unfortunately, d' cannot be used as an unbiased retention measure in animal research, because the assumptions of homogeneity of variance and normality of distribution have not been adequately demonstrated. In this case, however, the proportion of the area under the receiver operating curve (ROC), known as P(A), may be directly calculated from the data points (McNicol, 1972). The rationale of this approach can be readily understood by examination of Figure 1. Points on line A represent an equal proportion of hits and false alarms, and produce a P(A) value of .50, indicating no signal sensitivity or retention of the stimulus. However, if greater proportions of hits than false alarms are made, as indicated by points (x,y), (x',y'), and (x'',y''), the proportion of the total area under the resulting ROC will increase, and P(A) will become greater than .50. Thus, increased values of P(A) will reflect better signal sensitivity or retention.

Unfortunately, the response criteria of animals are not so

easily manipulated as to produce sufficient data points for the construction of receiver-operating-curves, or the calculation of P(A). Indeed, only one such data point is usually available. However, a point estimate of P(A), $P(\overline{A})$, has been developed to meet this need (Grier, 1971; McNicol, 1972; Pollack, 1970). The derivation of this measure can be understood by considering point (x,y) in Figure 1. Two lines can be drawn through this point, one from (0,0) (line B) and the other from (1,1) (line C) to the intercept on the y-axis. These two lines represent the lower and upper boundary (respectively) of an ROC that would produce the smallest and largest value of P(A) (respectively) with (x,y) as one of the data points. Given the uncertainty of which ROC data point (x,y) belongs to, the best estimate of P(A), yielding the lowest error, is the average of the sum of the areas under the upper and lower boundaries (lines C and B). Rather than determining $P(\overline{A})$ graphically, the equivalent algebraic formula may be used:

$$P(\overline{A})=(((y-x)(1+y-x))/(4y(1-x)))+0.5$$

where x represents the proportion of false alarms and y represents the proportion of hits (Cohen & Fuerst, 1985). Unlike d', the calculation of $P(\overline{A})$ (and P(A)) requires no assumptions about the normality of distribution or homogeneity of variance; it is a nonparametric measure of sensitivity.

Thus, $P(\overline{A})$, the point estimate of P(A), was chosen as the main dependent variable in this study. This decision was made for two specific reasons. First, this study utilized an asymmetrical reinforcement structure. As alluded to above,

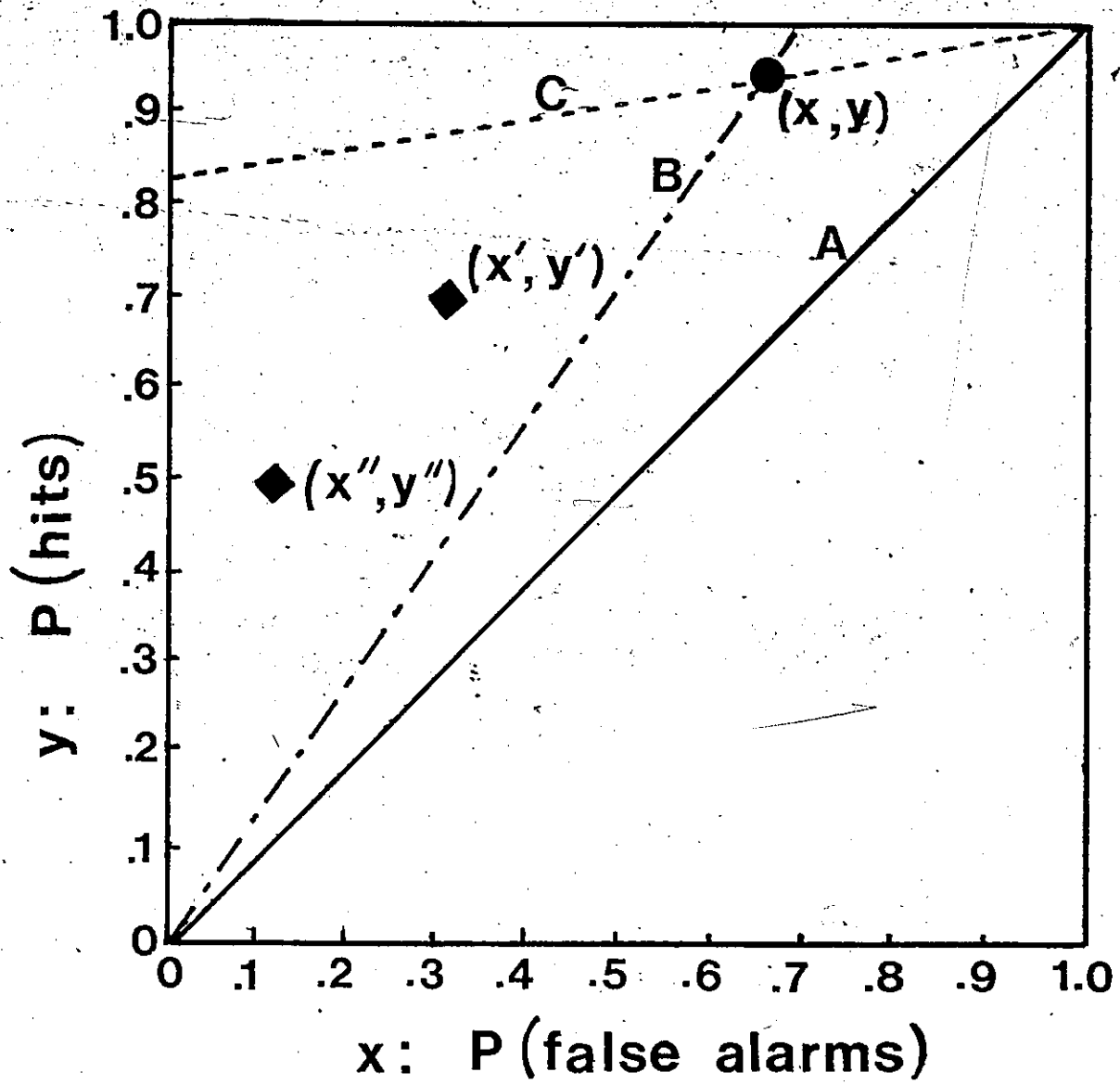


Figure 1. Points on line A represent equal proportions of hits and false alarms, and no retention of the stimulus. Lines B and C represent the lower and upper boundaries of an ROC through (x,y), and would produce the smallest and largest values of P(A) (respectively) with (x,y) as one of the data points.

Cohen et al. (1984) found empirical evidence that such a payoff structure tended to produce a relatively liberal response criterion. More conventional measures, such as percent correct or discrimination ratios, which do not take response bias into account, would most likely tend to underestimate S_1 retention with increased RI's. While the use of a symmetrical payoff structure, to directly attenuate bias to respond, in combination with $P(\overline{A})$ scores would have been preferred, the greater difficulty in training rats to learn symmetrically reinforced DMTS (Cohen & Fuerst, 1985) was deemed to be disproportionate to the potential benefits. Second, in a statistical comparison of percent correct, discrimination ratios, and $P(\overline{A})$ scores, Cohen and Fuerst (1985) found evidence that, of the three measures, $P(\overline{A})$ was most sensitive to stimulus modality effects in DMTS with rats, due to its attenuation of response bias.

Finally, two supplementary analyses were also performed. First, in order to compare the relative difficulty of unimodal light and tone DMTS, the days required to reach criterion under the Random SO condition in both Unimodal DMTS Training and Unimodal DMTS Reacquisition were calculated and compared. Second, to determine whether there were any consistent differences between light and tone S_1 retention during bimodal DMTS training, $P(\overline{A})$ scores for light and tone were calculated for each animal in each session during bimodal DMTS training with the Random SO presentation sequence. For each animal, graphs were constructed plotting $P(\overline{A})$ for light and tone S_1 as

a function of session, and visually inspected. Given the "noisy" nature of this data, smoothed curves were also generated using a spline interpolation algorithm, so that any trends present would become more apparent. For each animal, the proportion of sessions in which the $P(\overline{A})$ score for tone exceeded the $P(\overline{A})$ score for light was also calculated, and compared with the value expected by chance (.50) by means of a Binomial test.

CHAPTER III

Results

The proportion of reinforced (hits) and nonreinforced presses (false alarms) were calculated for each animal at baseline and test delay intervals. These values were used to calculate $P(\overline{A})$ scores, according to the formula given above. The proportions (hits, false alarms, and $P(\overline{A})$ scores) were subjected to arc sin transformations to normalize the data, and reduce its heterogeneity of variance, for parametric statistical analysis (Winer, 1971). A three-way analysis of variance (S_1 Modality [light, tone] X Retention Interval [5, 10, 20 s] X Testing [baseline delay interval, test delay interval]) with repeated measures on all factors was conducted on each dependent variable. Post hoc comparisons between individual means were carried out by Newman-Keuls tests, as suggested by Ferguson (1981).

The mean number of days required to reach criterion in the unimodal DMTS random stimulus order conditions were also calculated. These data were subjected to a two-way analysis of variance (S_1 Modality [light, tone] X Training Condition [training, reacquisition]), with repeated measures on all factors, and two separate one-way analyses of variance within each training condition (S_1 Modality [light, tone]) with repeated measures on this factor. In the final analysis in this study, $P(\overline{A})$ scores for light and tone on each day of bimodal DMTS training were calculated for each animal. The proportion

of total days where the $P(\overline{A})$ score for tone was greater than the $P(\overline{A})$ score for light were determined, for each animal, and compared to the expected value of .5 (no difference between light and tone) by means of a binomial test.

Days to Reach Criterion

Table 4 presents the mean number of days to reach criterion in both unimodal DMTS training (Random SO conditions) and unimodal DMTS reacquisition (Random SO conditions), for light and tone stimuli (see Table 3 for a summary of the procedure). Inspection of Table 4 indicated that there was a marked difference between visual and auditory stimuli, and little or no difference between training and reacquisition, in the number of days required to reach the criterion level of performance. This was confirmed by an analysis of variance (summarized in Table 5). There was a significant effect of S_1 Modality ($F[1,5] = 25.59$, $p < .01$), with the mean number of days to reach criterion with the visual S_1 being less than the mean number of days to reach criterion with the auditory S_1. There was no effect of Training Condition, or interaction between S_1 Modality and Training Condition, indicating that the animals reached criterion as quickly in Training as in Reacquisition. Not surprisingly, the effect of S_1 Modality was significant in both Training ($F[1,5] = 7.73$, $p < .05$) and Reacquisition ($F[1,5] = 57.43$, $p < .01$) conditions.

Proportion of Days Where $P(\overline{A})$ Was Greater For Tone

As stated above, $P(\overline{A})$ scores for light and tone, for each animal, were calculated for each day prior to the first testing

Table 4

Mean (Standard Deviation) Number of Days to Reach Criterion in Unimodal DMTS Random Stimulus Order Conditions

	Stimulus Modality		
Phase	Light	Tone	Combined
Training	9.17_a	27.33_a	18.25
	(11.70)	(17.48)	(17.06)
Reacquisition	7.00_b	21.17_b	14.08
	(3.35)	(3.37)	(8.06)
Combined	8.08_c	24.25_c	16.17
	(8.28)	(12.42)	(13.22)

Note. Means with the same subscript are significantly different at $p<.05$ (see Table 5).

Table 5

Summary of Analysis of Variance of Days to Reach Criterion In Unimodal DMTS for Stimulus Modality and Training Condition

Source of Variation	SS	df	MS	F	p
Training Condition in Model					
Stimulus Modality (S_1MOD)	1568.2	1	1568.2	25.59**	0.004
Error	294.8	5	58.9		
Training Condition (COND)	104.2	1	104.2	0.57	0.483
Error	905.8	5	181.2		
S_1MOD X COND	24.0	1	24.0	0.30	0.607
Error	398.0	5	79.6		
Condition = Training					
S_1MOD	990.1	1	990.1	7.73*	0.039
Error	640.4	5	128.1		
Condition = Reacquisition					
S_1MOD	602.1	1	602.1	57.43**	0.001
Error	52.4	5	10.5		

*$p < .05$

**$p < .01$

block in Bimodal DMTS. Graphs were constructed comparing P($\overline{A}$) scores for light and tone as a function of days. As this data contained a considerable amount of noise, versions of these curves smoothed by a spline interpolation algorithm were also generated (SASGRAPH option I=SM40). Given that this is not a common technique in behavioral research, and that, especially with behavioral data, there is always some uncertainty as to what constitutes "signal", and what constitutes "noise", both unsmoothed and smoothed versions of the graphs are presented in Figures 2 to 11. Each pair of even and odd numbered figures presents the unsmoothed and smoothed data, respectively, for one animal. Inspection of these figures, particularly the smoothed versions, suggested that there was a trend for P($\overline{A}$) scores for the auditory sample stimulus to be higher than P($\overline{A}$) scores for the visual sample stimulus. This tendency was most pronounced for animals 845, 847, and 863 (Figures 3, 5, and 9 respectively). As summarized in Table 6, binomial tests of the proportion of days where P($\overline{A}$) for tone was greater than P($\overline{A}$) for light (assuming $p=q=.5$) confirmed this observation. For animals 845, 847, and 863, P($\overline{A}$) for tone was higher than P($\overline{A}$) for light on more days than would be expected by chance ($p < .05$). While the proportions of days, where P($\overline{A}$) for tone was greater than P($\overline{A}$) for light, were not significantly different for animals 859 and 870, the values were in the same direction

Proportion of Hits (Reinforced Lever Presses)

Figure 12 shows the proportion of hits and false alarms

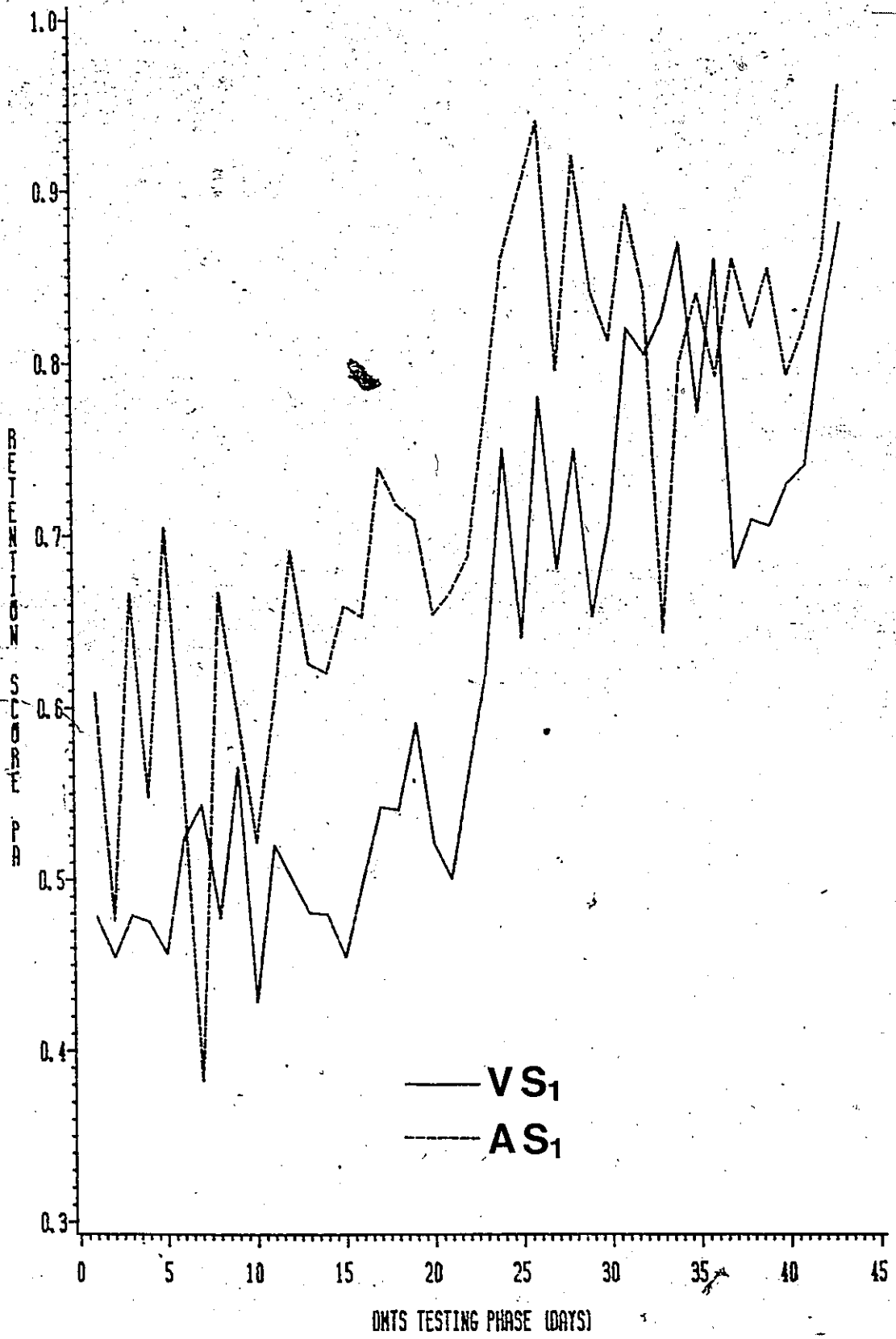


Figure 2. Retention scores ($P(\bar{A})$) for animal 845, in bimodal DMTS up to the first test block (RI=1 s), with visual and auditory sample stimuli (VS_1 and AS_1 respectively).

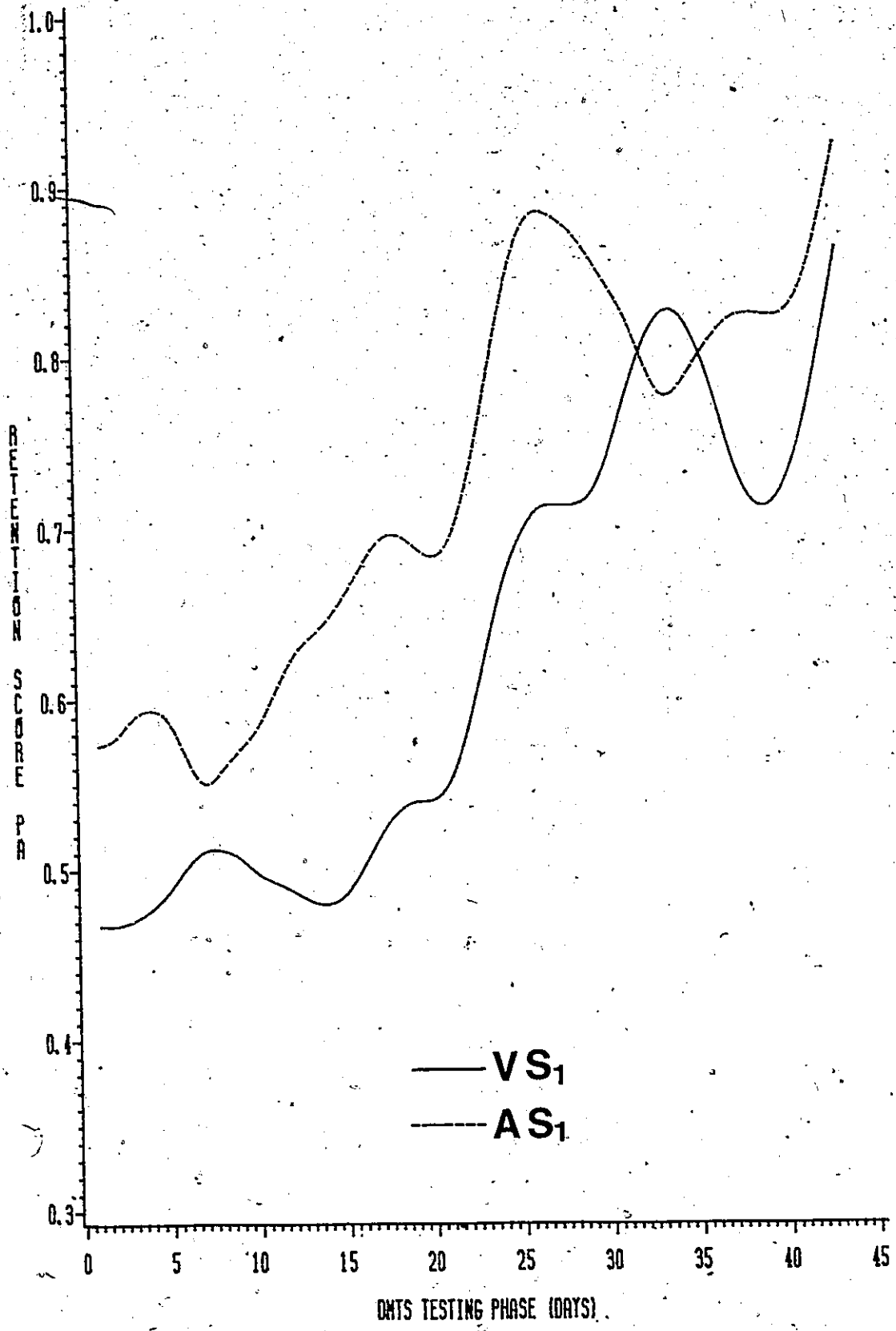


Figure 3. Smoothed retention scores ($P(\bar{A})$) for animal 845, in bimodal DMTS up to the first test block (RI=1 s), with visual and auditory sample stimuli (VS_1 and AS_1 respectively).

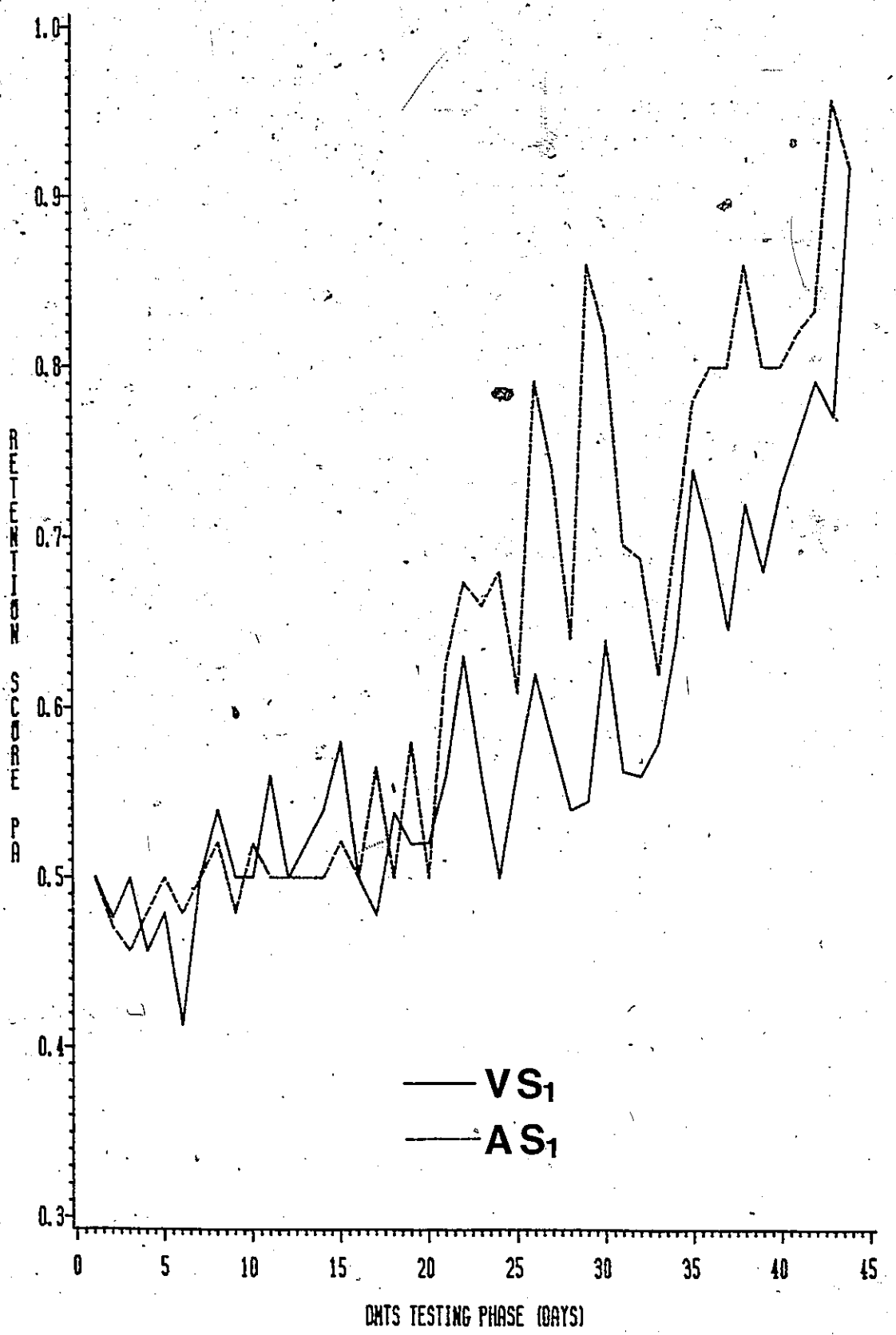


Figure 4. Retention scores ($P(\overline{A})$) for animal 847, in bimodal DMTS up to the first test block (RI=1 s), with visual and auditory sample stimuli (VS_1 and AS_1 respectively).

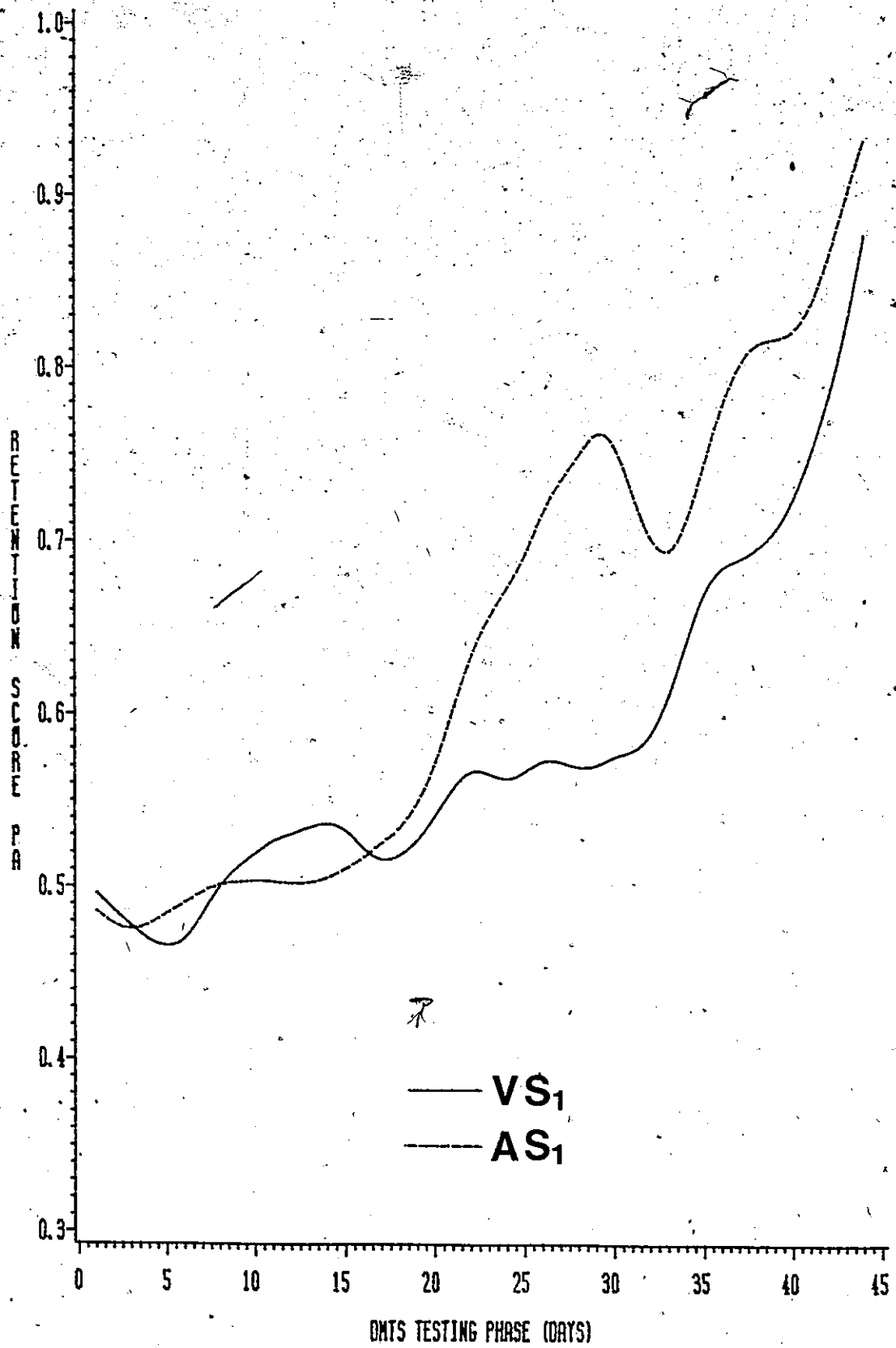


Figure 5. Smoothed retention scores ($P(\overline{A})$) for animal 847, in bimodal DMTS up to the first test block (RI=1 s), with visual and auditory sample stimuli (VS_1 and AS_1 respectively).

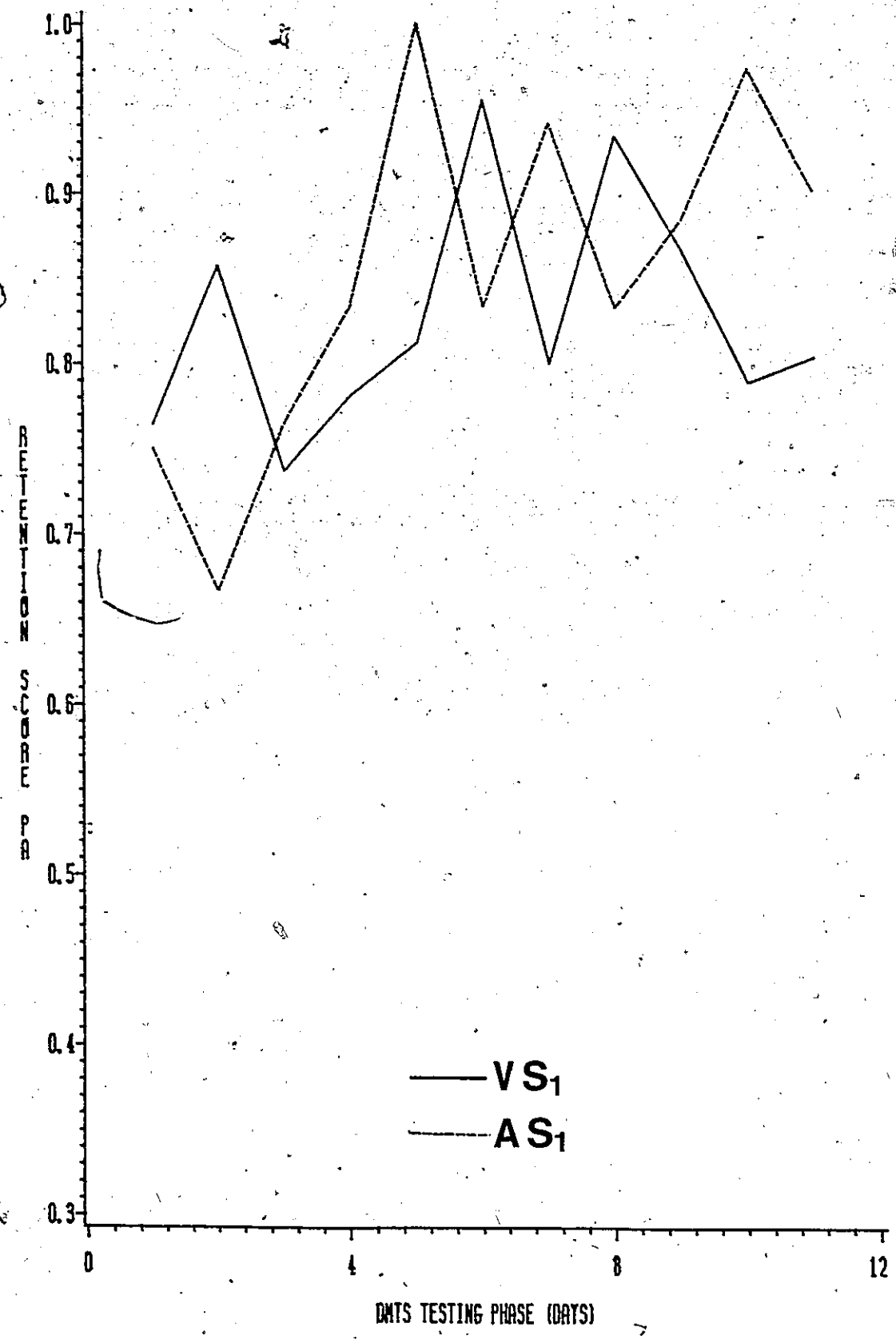


Figure 6. Retention scores ($P(\overline{A})$) for animal 859, in bimodal DMTS up to the first test block (RI=1 s), with visual and auditory sample stimuli (VS_1 and AS_1 respectively).

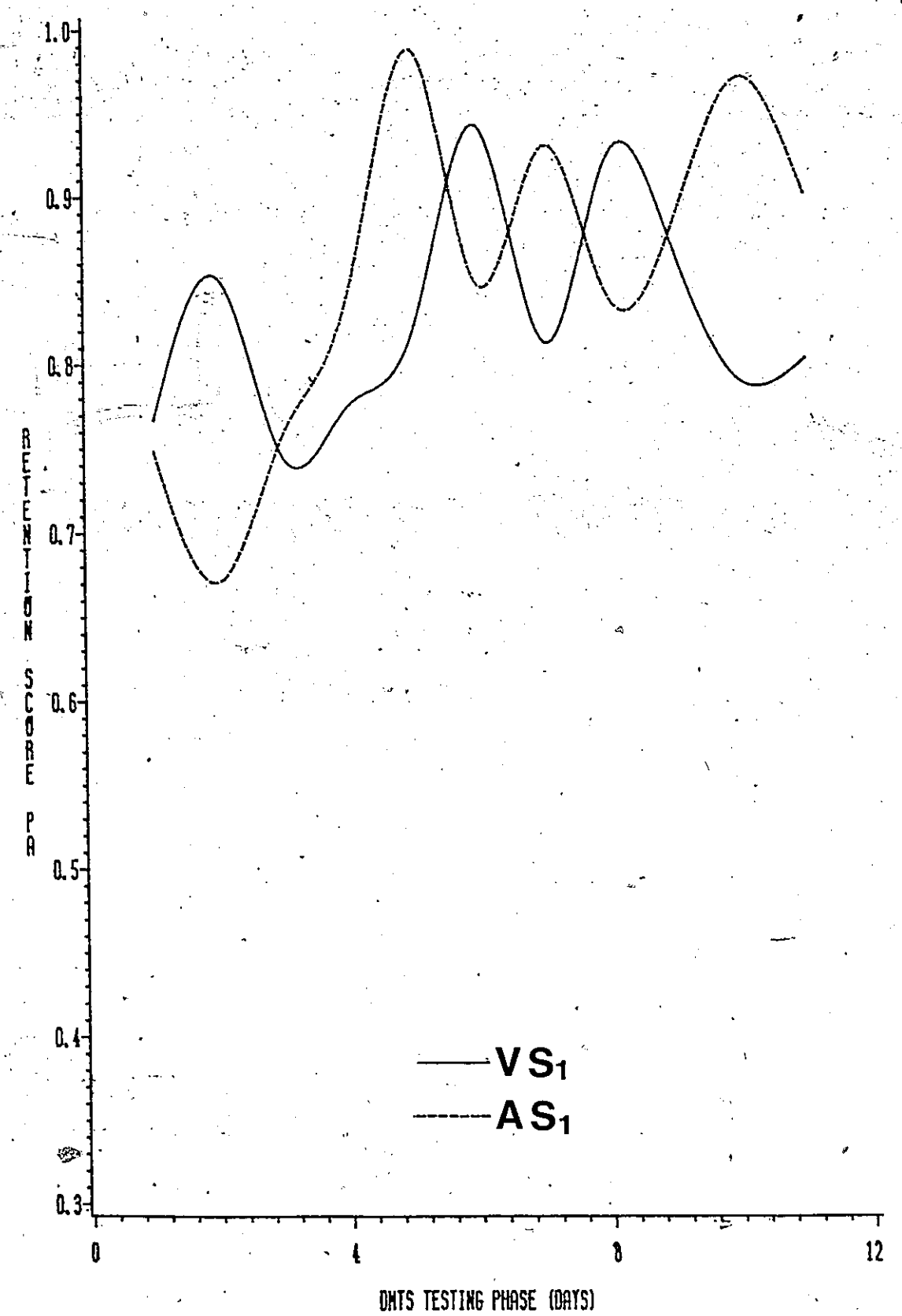


Figure 7. Smoothed retention scores ($P(\bar{A})$) for animal 859, in bimodal DMTS up to the first test block (RI=1 s), with visual and auditory sample stimuli (VS_1 and AS_1 respectively).

of invented gods; revenge and pettiness instead of confidence and stregth directed toward challenging and perhaps even dangerous goals. Christianity represents, in Nietzsche's view, hatred of life and a lack of really affirmative power. Strong, threatening imulses are branded "evil" and extirpated rather than being controlled and channelled; actual existence is scuttled in favour of "another", "higher" world; humility and "brotherly love" are held up as ideals but only out of fear and weakness ("When stepped on, a worm doubles up. That is clever. In that way he lessens the probability of being stepped on again. In the language of morality: humility." (G I 31)); man prostrates himself before "gods", though his devotion to them merely provides an excuse to inflict narrow-mindedness on others; obstacles and resistance and incapacity are not regarded as calls to battle but as proof of the inherent wretchedness of life; lack of practical and spiritual power instigates not genuine remedial action but programmatic retribution against the gifted, who are denounced as "prideful" and "godless". The Christian orientation is the antipode to a healthy orientation, that is to say, one founded in vital capacity which embraces the world, such as it is, and strives to enhance itself.

The highest religious and moral values of the West signify, according to Nietzsche, a lack of life-affirmation, and hence of life. They signify, to put it another way, spiritu-

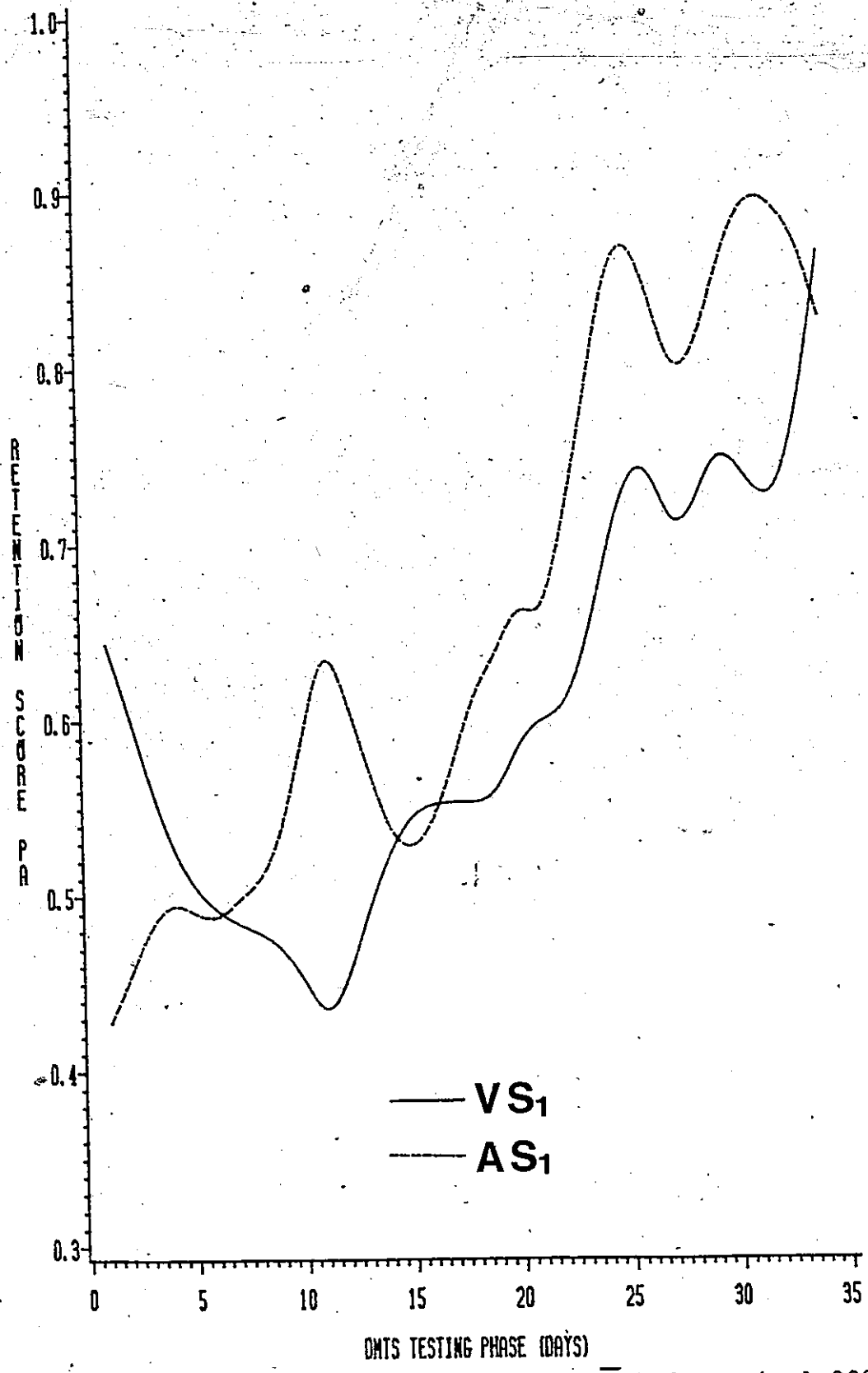


Figure 9. Smoothed retention scores ($P(\overline{A})$) for animal 863, in bimodal DMTS up to the first test block (RI=1 s), with visual and auditory sample stimuli (VS_1 and AS_1 respectively).

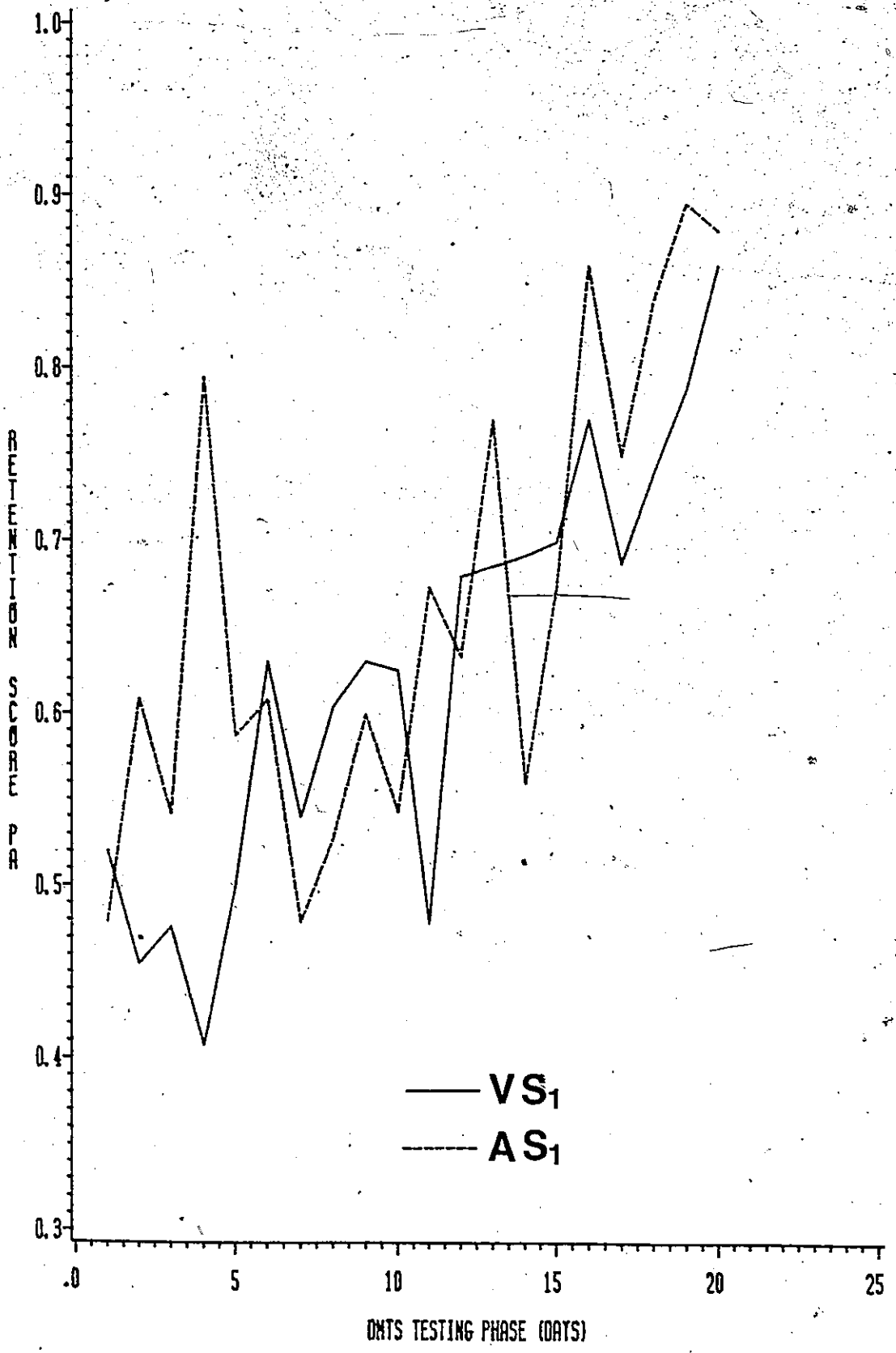


Figure 10. Retention scores ($P(\overline{A})$) for animal 870, in bimodal DMTS up to the first test block (RI=1 s), with visual and auditory sample stimuli (VS_1 and AS_1 respectively).

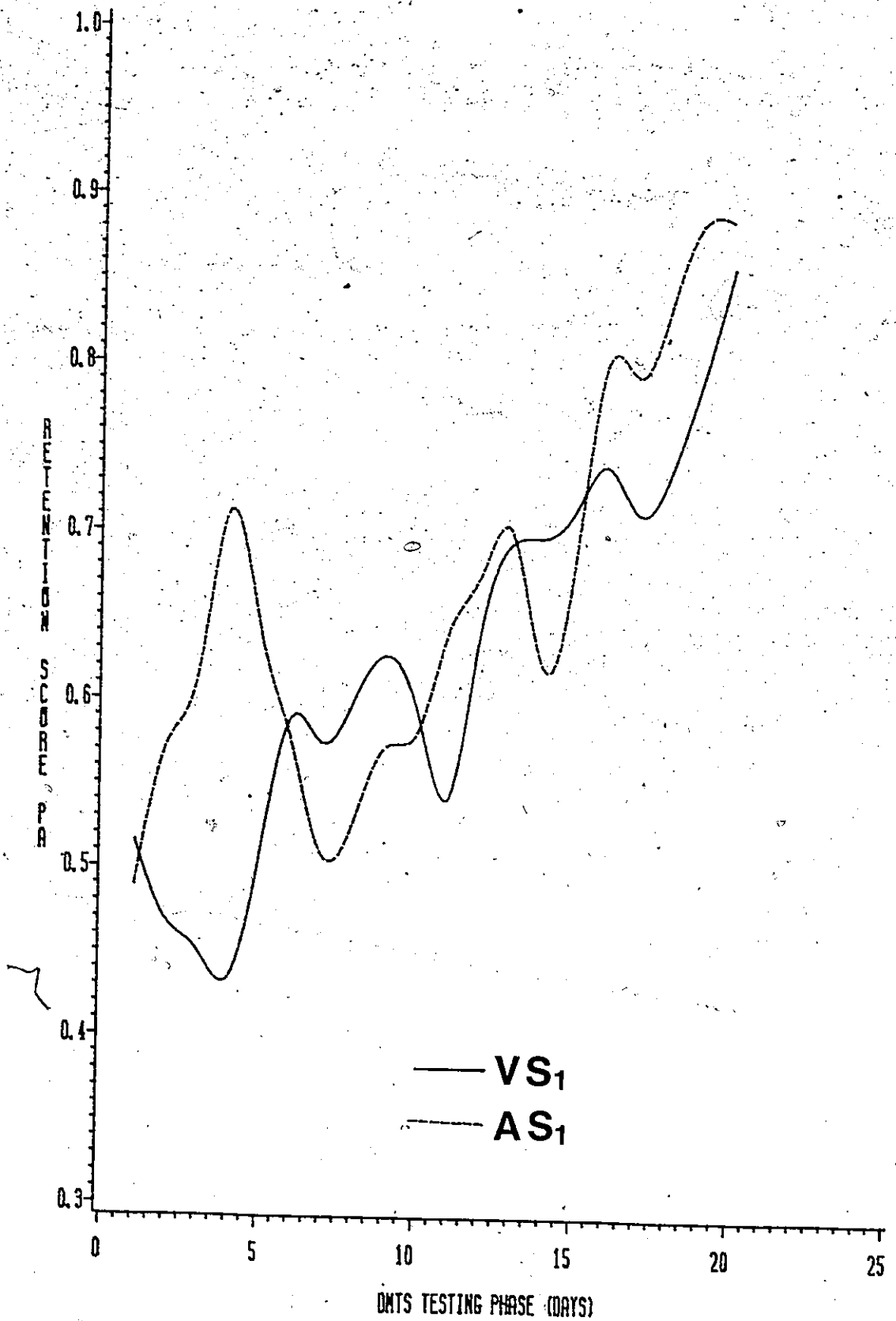


Figure 11. Smoothed retention scores ($P(\overline{A})$) for animal 870, in bimodal DMTS up to the first test block (RI=1 s), with visual and auditory sample stimuli (VS_1 and AS_1 respectively).

Table 6

Proportion of Days For Each Animal When $P(\bar{A})$ For Tone Was Greater Than $P(\bar{A})$ For Light During Bimodal DMTS Training

Animal	Total Days	Frequency Tone Greater	Proportion	p
845	43	39	.907*	.000
847	44	29	.659*	.013
859	11	7	.636	.160
863	34	23	.676*	.016
870	20	11	.550	.160

*$p < .05$

(nonreinforced presses) at each baseline (1 s RI) and test delay interval (5, 10, and 20 s RI). As seen in Figure 12, reinforced responses declined from baseline levels at test delay intervals only for the visual S_1. Hits to the auditory S_1 showed no change at delays greater than baseline (1 s). Results of the analysis of variance (summarized in Table 7) confirmed these observations. Overall, there was a main effect of Testing ($F[1,4] = 22.09$, $p < .01$), with hits declining at delays greater than baseline. There was also a significant interaction of S_1 Modality X Testing ($F[1,4] = 42.13$, $p < .01$), with hits to the visual S_1 showing a significant decline at delays greater than baseline ($p < .05$), but no change in hits to the auditory S_1. Furthermore, at baseline delay intervals (1 s), significantly more hits were made to the visual S_1 ($p < .05$); however at delays greater than 1 s significantly more hits were made to the auditory S_1 ($p < .01$).

Proportion of False Alarms (Nonreinforced Presses)

As shown in Figure 12, at delays greater than 1 s there was an increase in false alarms to both the visual and auditory sample stimuli. However, this increase appeared to be somewhat more pronounced for false alarms to the visual S_1. An analysis of variance (summarized in Table 8) confirmed these observations. Overall, there was a significant increase in false alarms at delay intervals greater than baseline ($F[1,4] = 24.04$, $p < .01$). In addition, there was a significant interaction of S_1 Modality and Retention Interval ($F[2,8] = 13.24$, $p < .01$). Individual comparisons indicated that, pooled

Figure Caption

Figure 12. Mean proportion of reinforced presses (RP) and nonreinforced presses (NRP) at each baseline (1 s) and test (5, 10, 20 s) retention interval for visual and auditory sample stimuli (VS_1 and AS_1 respectively).

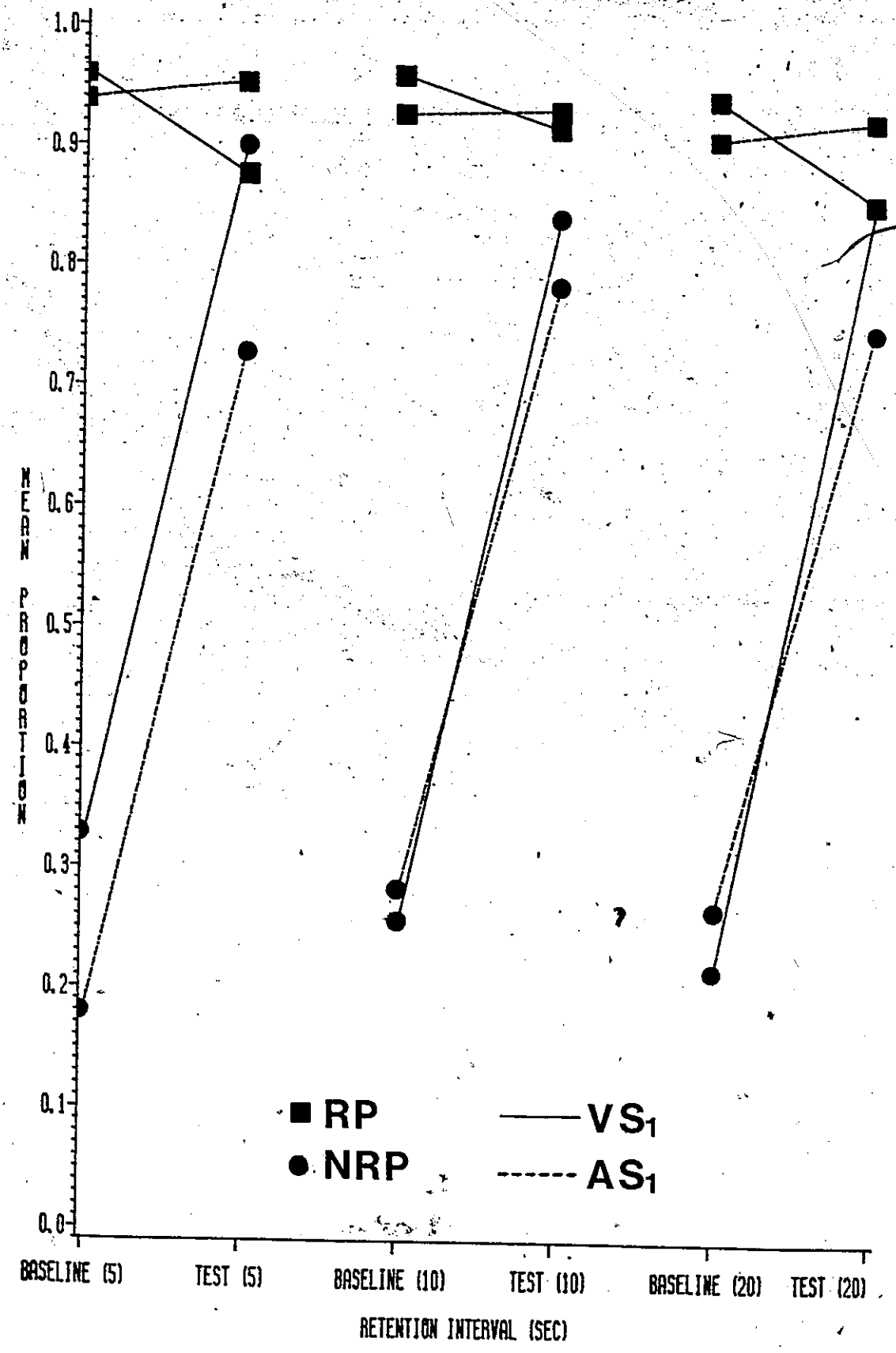

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
MEAN PROPORTION
RP
NRP
VS1
AS1
BASELINE (5)
TEST (5)
BASELINE (10)
TEST (10)
BASELINE (20)
TEST (20)
RETENTION INTERVAL (SEC)

Table 7

Summary of Analysis of Variance of Hits for Stimulus Modality, Retention Interval, and Testing

Source of Variation	SS	df	MS	F	p
Stimulus Modality (S_1MOD)	0.055	1	0.055	2.37	0.198
Error	0.093	4	0.023		
Retention Interval (RI)	0.353	2	0.177	1.81	0.224
Error	0.780	8	0.098		
Testing (TEST)	0.209	1	0.209	22.09*	0.009
Error	0.038	4	0.010		
S_1MOD X RI	0.052	2	0.026	1.06	0.391
Error	0.196	8	0.025		
S_1MOD X TEST	0.650	1	0.650	42.13*	0.003
Error	0.062	4	0.016		
RI X TEST	0.113	2	0.057	0.59	0.577
Error	0.765	8	0.096		
S_1MOD X RI X TEST	0.010	2	0.005	0.25	0.783
Error	0.157	8	0.020		

*$p < .01$

Table 8

Summary of Analysis of Variance of False Alarms for Stimulus Modality, Retention Interval, and Testing

Source of Variation	SS	df	MS	F	p
Stimulus Modality (S_1MOD)	0.513	1	0.513	4.43	0.103
Error	0.463	4	0.116		
Retention Interval (RI)	0.045	2	0.023	0.39	0.688
Error	0.460	8	0.058		
Testing (TEST)	24.043	1	24.043	24.04*	0.002
Error	1.661	4	0.415		
S_1MOD X RI	0.545	2	0.273	13.24*	0.003
Error	0.165	8	0.021		
S_1MOD X TEST	0.232	1	0.232	3.79	0.123
Error	0.245	4	0.061		
RI X TEST	0.017	2	0.009	0.65	0.549
Error	0.108	8	0.014		
S_1MOD X RI X TEST	0.038	2	0.019	0.88	0.452
Error	0.175	8	0.022		

*$p < .01$

across Testing (i.e. baseline and test delays), there was a greater increase in false alarms to light as compared to tone ($p < .05$) at 20 s RI. Also, at test RIs the only significant difference between light and tone was at the 5 s delay interval ($p < .05$).

P($\overline{A}$) Retention Scores

Figure 13 shows the mean retention scores (P($\overline{A}$)) at each baseline (1 s RI) and test delay interval (5, 10, and 20 s RI). Inspection of Figure 13 indicated that retention of both visual and auditory sample stimuli declined at retention intervals greater than 1 s. Furthermore, it was apparent that declines in the retention of the visual S_1 were greater than declines in the retention of the auditory S_1. These observations were confirmed by an analysis of variance (summarized in Table 9). Significant effects were found for both Testing ($F[1,4] = 85.16$, $p < .01$), due to an overall decline in P($\overline{A}$) scores at delays greater than 1 s, and S_1 Modality ($F[1,4] = 43.06$, $p < .01$), due to overall lower retention scores to the visual S_1. There was also a significant S_1 Modality X Testing interaction ($F[1,4] = 41.68$, $p < .01$). Individual comparisons indicated that, while there was no difference between visual and auditory P($\overline{A}$) scores at baseline delay intervals, at RIs greater than 1 s, retention scores for light were significantly lower than retention scores for tone ($p < .01$).

Figure Caption

Figure 13. Mean retention score ($P(\overline{A})$) at each baseline (1 s) and test (5, 10, 20 s) retention interval for visual and auditory sample stimuli (VS_1 and AS_1 respectively).

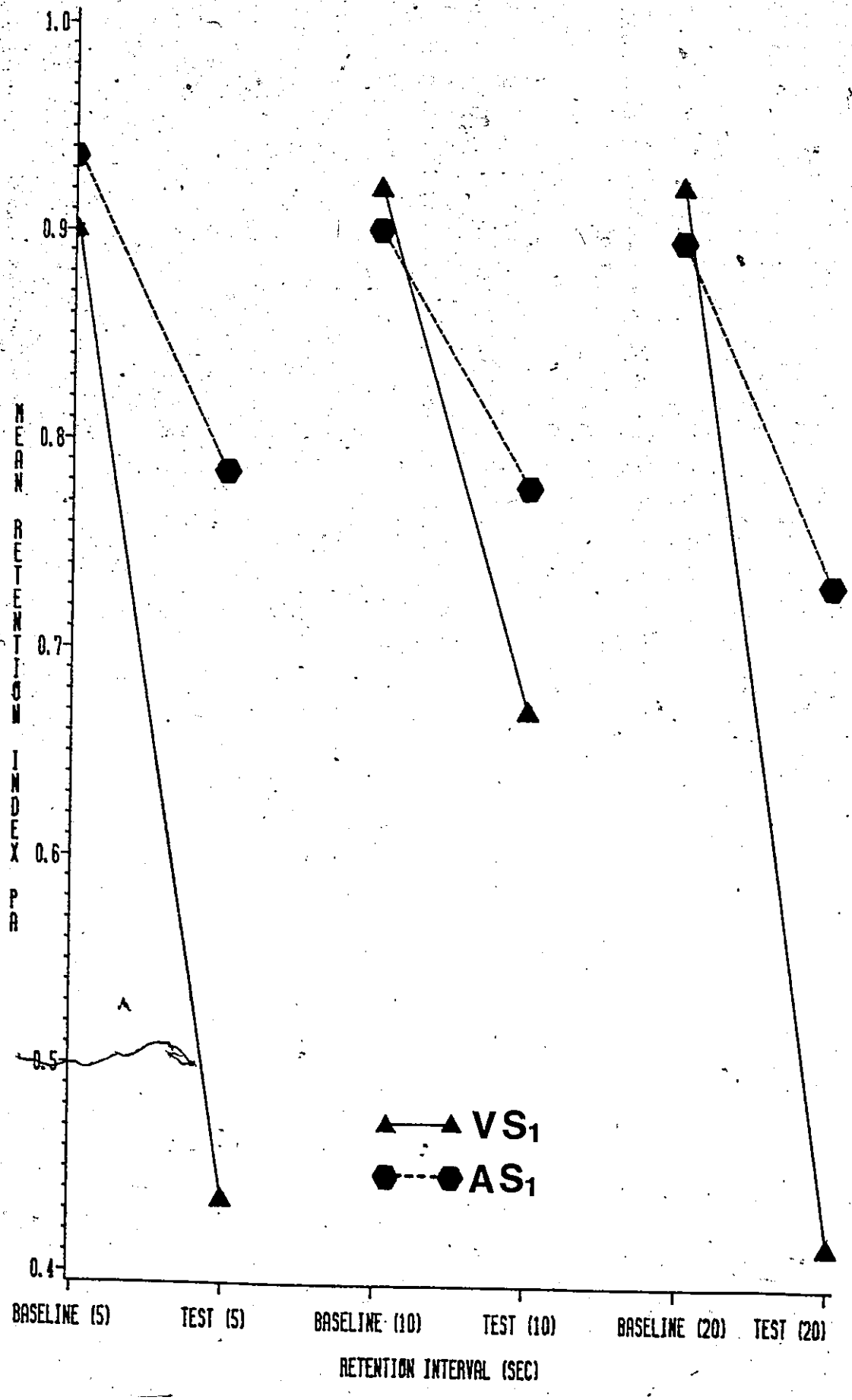

1.0
0.9
0.8
0.7
0.6
0.5
0.4
MEAN RETENTION INDEX PR
VS1
AS1
BASELINE (5)
TEST (5)
BASELINE (10)
TEST (10)
BASELINE (20)
TEST (20)
RETENTION INTERVAL (SEC)

Table 9

Summary of Analysis of Variance of $P(\overline{A})$ for Stimulus Modality, Retention Interval, and Testing

Source of Variation	SS	df	MS	F	p
Stimulus Modality (S_1MOD)	1.175	1	1.175	43.06*	0.003
Error	0.109	4	0.027		
Retention Interval (RI)	0.306	2	0.153	1.93	0.207
Error	0.635	8	0.079		
Testing (TEST)	7.390	1	7.390	85.16*	0.001
Error	0.347	4	0.087		
S_1MOD X RI	0.326	2	0.163	2.73	0.125
Error	0.478	8	0.060		
S_1MOD X TEST	1.248	1	1.248	41.68*	0.003
Error	0.120	4	0.030		
RI X TEST	0.340	2	0.170	1.83	0.222
Error	0.743	8	0.093		
S_1MOD X RI X TEST	0.168	2	0.084	1.38	0.307
Error	0.488	8	0.061		

*$p < .01$

CHAPTER IV

Discussion

On the basis of the analyses of hits, false alarms, and $P(\overline{A})$ scores in bimodal DMTS testing, the specific expectation as to the effect of training was not confirmed. While the details differed slightly with respect to each dependent measure, overall, at delays greater than 1 s, the visual sample stimulus appeared to be less well remembered than the auditory sample stimulus. With increased RIs, retention indices for the tone stimulus either remained at baseline levels of performance (hits), or declined less than retention indices for the light sample stimulus (false alarms and $P(\overline{A})$ scores). Thus, extensive training with unimodal DMTS did not eliminate the stimulus modality effect on testing with bimodal DMTS. This result is in agreement with the dual-storage model of rat working memory proposed by Cohen et al. (1984). If the stimulus modality effect is due to differences in functional properties of modality specific memory stores, one would not expect experiential factors (such as training) to modify the effect.

Considering the rather large number of trials involved in the massed practice phases of this study (a minimum of 3200 trials with each stimulus modality) it is difficult to attribute this result to insufficient training. It would seem unlikely that even more lengthy practice with unimodal DMTS would substantially alter these results. In addition, it should be noted that only five subjects completed the testing phase of

the study. If the stimulus modality effect had not been observed, there would have been some doubt as to whether failure to find a significant effect could be due to the small sample size, and concomitant low power of the statistical tests used, or to the training procedure. However, even with just five subjects, statistically significant results were found, which implies a rather large effect for S_1 modality. Thus, the stimulus modality effect does indeed appear to be a very robust, consistent, characteristic of bimodal successive delayed matching to sample by the rat.

The trends in $P(\overline{A})$ scores for light and tone across bimodal DMTS training also illustrated this feature. There was a clear tendency for tone retention scores to be higher than the light retention scores for three of the five animals which completed this phase of the study. However, while the stimulus modality effect found in bimodal DMTS testing would appear to support a dual-process model of working memory (as massed practice did not eliminate the stimulus modality effect), the influence of stimulus modality found in training may not. This is simply because it is difficult to interpret the training task as a test of working memory, as the retention interval involved was only one second. At such a short delay, it is likely that there is comparatively little demand placed on working memory. Why should the effect be found in a task which may not be primarily dependent on working memory? Explanations of the S_1 modality effect which rely on (hypothetical) retrospective memory processes would not seem to be applicable

in this case.

The analysis of the number of days to reach criterion in the unimodal DMTS training phases also seemed to suggest that the modality specific retrospective memory model of the stimulus modality effect may not be correct. Overall, matching to a visual sample stimulus was learned about three times more quickly than matching to an auditory sample stimulus (8 days versus 24 days, respectively). This instance of better performance to visual stimuli as opposed to auditory stimuli is an interesting contradiction to the other results found in this study, and in previous research. This finding cannot be accounted for by the modality specific retrospective memory model for two reasons. First, if one assumes that retrospective working memory processes are important in successive DMTS, even at a one second RI, this result would suggest better retention/retrieval of visual stimuli as opposed auditory stimuli. Such a position would be in direct contradiction with the proposal of Cohen et al. (1984), which suggests precisely the opposite state of affairs in rat working memory. Second, if one accepts that successive DMTS with a one second RI places little demand on working memory, hypothetical functional properties of working memory (such as retention and retrieval) would be of little use in explaining the result. However, the result is entirely in agreement with the model of the stimulus modality effect proposed in this paper. If visual stimuli are indeed more accurately encoded than auditory stimuli, one would expect faster acquisition of unimodal DMTS with light sample

stimuli. On the other hand, if auditory stimuli are not accurately or completely encoded by the animal, one would expect much slower acquisition of the task.

To summarize, modest support was found for the "differential encoding" hypothesis proposed in this paper. Although retention of auditory stimuli appeared to be better than retention of visual stimuli in the bimodal DMTS test conditions, a finding which is in agreement with all previous research in this area, other information from different phases of the study did not agree with the retrospective modality specific storage model of working memory. In particular: 1) in bimodal DMTS with a one second RI the S_1 modality effect was found, even though retrospective working memory processes probably did not play a critical role in performance of the task; 2) in unimodal DMTS training animals acquired the task more quickly with visual as opposed to auditory stimuli. These findings are consistent with the hypothesis that rats encode auditory stimuli more poorly than visual stimuli.

This conclusion is, of course, dependent on post hoc analysis and interpretation of the results. It must also be noted that the principle expectation of this study, that extensive training would eliminate the stimulus modality effect, was not confirmed. Unfortunately, the design of the study did not permit an accurate evaluation of the strength of the S_1 modality effect after unimodal DMTS training. The unanswered question is whether massed practice produced attenuation rather than elimination of the effect. Such a

finding would provide support for the differential encoding explanation of the stimulus modality effect. Current research in our laboratory is attempting to address this issue by interpolation of unimodal DMTS training between bimodal DMTS testing phases. This will allow direct assessment of changes in the strength of the effect as a result of unimodal DMTS training. Furthermore, we have modified the unimodal training procedures such that both stimulus modalities are present but only one is relevant to the task (for example, in unimodal light training tone is made redundant by presentation on all trials, so the animal must match only on the basis of light stimuli). Although this study is still in progress, preliminary results indicate that the animals are unable to learn unimodal DMTS to tone stimuli with light being redundant; however, they are able to rapidly acquire unimodal DMTS to light stimuli with tone being redundant. These early, and incomplete, results are consistent with the encoding hypothesis of the stimulus modality effect. In any event, this, and similar, research is representative of important first steps in an understanding of complex animal behavior. Future progress in animal cognition will ultimately depend on a clear delineation and better understanding of the particular processes and factors involved in the performance of higher-order behaviors.

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[2]ibid., p. 14.

[3]Hollingdale, Nietzsche, p. 158.

[4]Pasley, in Nietzsche: Imagery and Thought, p. 157.

[5]Deleuze, Nietzsche and Philosophy, p. 42.

[6]I believe that this substitution is in line with the sense of Deleuze's terms.

[7]See, for example, WM 855, 857.

[8]Pasley, in Nietzsche: Imagery and Thought, p. 148.

[9]ibid., p. 147.

[10]One of Nietzsche's main ideas. See, for instance, Z IV 13.

[11]WM 864.

[12]Friedrich Nietzsche, "The Philosopher as Cultural Physician", in Philosophy and Truth: Selections from Nietzsche's notebooks of the early 1870's, pp. 69-76, trans. and ed. Daniel Breazeale (Atlantic Highlands, New Jersey: Humanities Press, 1979).

[13]See, for example, G IV.

[14]Cited by Pasley, in Nietzsche: Imagery and Thought, p. 124.

[15]EH Z 2

Conclusion

[1]Pasley, in Nietzsche: Imagery and Thought, p. 157.

[2]Walter Kaufmann, ed., The Portable Nietzsche (New York: The Viking Press, 1968; reprint ed., Penguin Books, 1980), p. 465.

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